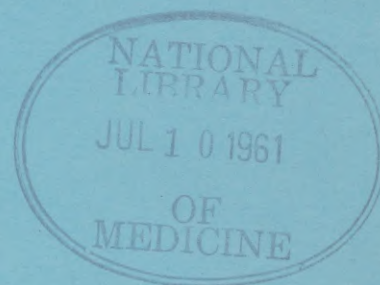# MINUTES AND PROCEEDINGS
of the Thirty-fourth meeting of the
ARMED FORCES-NRC VISION COMMITTEE
April 1-2, 1954

Department of the Interior Auditorium

Washington, D. C.

MINUTES AND PROCEEDINGS
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ARMED FORCES — NRC VISION COMMITTEE

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AGENDA OF THE 34TH MEETING
AND
INDEX TO THE PROCEEDINGS

OTHER PAPERS PRESENTED:

Mr. Carroll T. White of the U.S. Navy Electronics Laboratory
presented a paper entitled "The Use of Photographic 'Time-
Compression' Techniques with Radar and Sonar Data", the text
of which is not contained in this Proceedings volume since the
paper is CONFIDENTIAL.

Mr. Malcolm Lichtenstein of the U.S. Navy Electronics Laboratory
presented a paper entitled "Comparison of Four Different PPI
Displays for Sonar Detection", the text of which is not contained
in this Proceedings volume since the paper is CONFIDENTIAL.

Dr. H. W. Rose presented a paper entitled "Chorioretinal Burns
Produced by Atomic Flash" by Col. V. A. Byrnes, USAF (MC),
Capt. D. V. L. Brown, USAF (MC), Dr. H. W. Rose, and Dr.
P. A. Cibis, all of the USAF School of Aviation Medicine, Randolph
Field, Texas. The paper is not contained in this Proceedings vol-
ume since it is CONFIDENTIAL.

Dr. Glenn A. Fry presented a paper entitled "A Recent Study of
Chromatic Adaptation." There is no text of this paper available
for this Proceedings volume. The interested reader is referred
to a full report of this research included in Final Report (Phases
I, II, III, and IV), Contract Nonr-1066(00), Project No. NR 140-
061, March 1954.

Dr. S. Q. Duntley presented a paper entitled "A Program of
Research in Atmospheric Optics." There is no text of this paper
available for this Proceedings volume.

ARMED FORCES-NRC VISION COMMITTEE

Minutes of the Thirty-Fourth Meeting

April 1-2, 1954

Department of the Interior Auditorium
Washington, D.C.

The following were present:

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	Research Center	**(A)	Dr. H. D. Edwards
			Dr. Vincent Stakutis
	ADC	(M)	Brig. Gen. A. H. Schwichtenberg
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			Dr. Lynn E. Baker
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	OCAFF, Fort Knox		Mr. Howard C. Olson
	Human Research Unit No. 1		Mr. Norman Willard, Jr.
			Maj. Bert Nishimura
	OCAFF, Fort Benning		Lt. Charles K. Ramond
	Human Research Unit No. 3		
	AGO	(M)	Dr. Julius Uhlaner

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** (A) indicates Alternate Members appointed from military organizations.

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		Dr. Walter C. Gogel
	Army Med. Serv. Grad. Sch.	(M) Dr. John C. Armington
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		Dr. Robert S. Wiseman
	QMG	(A) Dr. John Kobrick
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INTRODUCTION AND SUMMARY: EVALUATION OF THE AMERICAN OPTICAL COMPANY VISION TESTER 1245 MG

Louise L. Sloan
The Johns Hopkins University

Glenn A. Fry
Ohio State University

B. J. Wolpaw
Cleveland, Ohio

In the latter part of 1952, the American Optical Company introduced to the Armed Forces, a new vision testing device. This device was more compact, lighter in weight, and more portable than the previously recommended Armed Forces Vision Tester. The device was 9-11/16" wide and 11-5/8" deep. The weight was 13-3/4 lbs. (Figure 1).

The instrument had two major innovations: first, all slides were incorporated in one roll of 35 mm. film; and second, an optical assembly which permits distance vision to be measured at a simulated 26 feet and near vision at 13 inches. The transition from far to near is automatically accomplished when the viewing box is changed from a horizontal to a down-angled position. The film strip can be seen with the exposed slides in Figure 2.

Figure 1

Figure 2

8

A working group was organized within the Armed Forces--NRC Vision Committee to evaluate this new device and to conduct comparative tests between this device and the previously approved Armed Forces Vision Tester and wall chart.

The American Optical Co. device will be referred to hereafter as AO and the Armed Forces Vision Tester as AFVT.

The working group met on May 7, 1953 at the Wilmer Ophthalmological Institute.

Present at the meeting were:

Captain John T. Smith	MC USN
Lt. Col. John W. Sheridan	MSC USA
Dr. J. E. Uhlaner	AGO
Dr. M. R. Marks	AGO
Dr. D. Gordon	AGO
Dr. A. Morris	Medical Research Laboratory, New London
Dr. B. Wild	Medical Research Laboratory, New London
Dr. H. C. Olson	Human Research Unit, Fort Knox
Dr. Henry Imus	ONR
Dr. Louise Sloan	Wilmer Institute
Dr. Glenn Fry	Ohio State University
Dr. B. J. Wolpaw	Chairman

In order to expedite the evaluation of this new device, the project was divided into six sections and each participating group was assigned specific tasks, as follows:

1. Comparison of Armed Forces Wall Chart vs. AO device.
   (a) AGO
   (b) Submarine Base

2. Comparison of AO vs. AFVT
   (a) School of Aviation Medicine, Pensacola
   (b) School of Aviation Medicine, Randolph Field

3. Test—Retest AO
   (a) Fort Knox

4. Phorometer vs. AO
   (a) Pensacola
   (b) Randolph Field

5. Depth Perception AO vs. AFVT
   (a) Fort Knox
   (b) Pensacola

6. Near Vision
   (a) Fort Knox
   (b) Pensacola
   (c) Submarine Base

Through the kindness of Brig. Gen. Earl Maxwell, USAF, five new model Armed Forces Vision Testers were obtained on loan from the Air Force to use in this project. The committee is indebted to Gen. Maxwell for his aid in obtaining these instruments.

The testing program was carried on through the summer of 1953 and the entire working group met again at Fort Knox during the fall meeting of the Vision Committee. At this

meeting, each participant presented a brief summary of his observations and data. The unanimity of findings was surprising. Although certain workers were restricted to personnel who had been previously screened and hence did not have a wide range of visual acuities, such as the Submarine Base, others were able to obtain examinees running the complete scale from 20/400 to 20/10.

A study of the detailed reports which follow will show that there were variations in the routine employed by the five participants. In spite of this, the results particularly with respect to visual acuity, were very similar.

The five independent reports were reviewed by Drs. Sloan, Fry and Wolpaw and the following summary and conclusion agreed upon.

Summary:

1. Visual Acuity
   All co-workers found consistently a significant lower acuity from 20/30 and better levels with the AO device than was present with either the wall chart or AFVT.

2. Phoria—Lateral and Vertical
   It is difficult to evaluate these tests. The results obtained with a maddox rod are not comparable to the results obtained with either instrument and their relationship is not fully understood.

   The near lateral slide on the AO was difficult to use because of the two fixation letters and caused some operational confusion.

3. Stereopsis
   The two instruments gave very similar results. This does not mean that either instrument provides the desired and best test for depth perception. It was disconcerting to note the large number of complete failures on both devices.

4. There are several mechanical improvements which can be made on the AO device. The need for these improvements are outlined in the individual reports.

Conclusion:

The American Optical Company Vision Tested (1245 MG) as submitted to the working group is not satisfactory.

AMERICAN OPTICAL COMPANY VISION TESTER EVALUATION:
100 CASES STUDIED

Thomas G. Dickinson, Lt., USN(MC)
U.S.N. School of Aviation Medicine
Pensacola, Florida

INTRODUCTION AND SUMMARY

This study is being undertaken in order to evaluate the relative correlation between the Armed Forces visual tester and the AO Experimental Armed Forces visual tester, and to compare both with the wall chart AO #1930 and phorometer method of visual testing.

One hundred cases have thus far been studied. The first 25 used the AO instrument first. The second 25 used the AFVT machine first and the following 50 were alternated on each test. In each case, wall chart and phorometer readings were done before the subjects were tested on the instruments. Ten tests were run on each subject. The six for distance were (1) vertical phoria, (2) lateral phoria, (3) letter acuity OD, (4) letter acuity OS, (5) fusion and depth perception. The five for near were (6) vertical phoria, (7) lateral phoria, (8) letter acuity OD, (9) letter acuity OS, and (10) prism divergence at near.

Tests number 8 and 9 were not done on the phorometer. Test number 10 was not done on the AFVT machine due to lack of equipment.

ANALYSIS OF DATA

Analysis of the data collected suggest the following interpretations:

Test (1) Vertical Phoria Distance
    The AO instrument shows a significant increase in number of R.H., and decrease in orthophoria over the phorometer or the AFVT. The AFVT shows slight increase in number of L.H., but AFVT compares favorably with the phorometer.

Test (2) Lateral Phoria Distance
    The AO instrument compares favorably with the phorometer. The AFVT instrument shows a significant increase in number of esophorias and decreased in number of exophorias.

Test (3) Acuity OD Distance
    The AO instrument shows a significantly fewer number of 20/20 subjects than the wall chart of AFVT with an increase in number of those below 20/20. The AFVT instrument, while showing slightly fewer 20/20 than the wall chart, compares favorably with it.

Test (4) Acuity OS Distance
    The results on the test are similar to test No. 3.

Test (5) Depth Perception
    The AO instrument showed a very slightly lower mean than the AFVT. The results, however, are favorably comparable.

Test (6) Vertical Phoria — Near

As in test 1, the AO instrument shows a significant increase in number of R.H. over the AFVT or wall chart, both of which compared favorably.

Test (7) Lateral Phoria — Near

It is difficult to compare the results in the test, as the AO and AFVT instruments use targets the same in principle but different in technical detail. The "V" in the AO target proved a source of confusion and I feel caused many unreliable results. The AFVT machine compared favorably but the AFVT shows a fewer number of exophorias and greater number of esophoria. The AO had over on-half of the subjects showing orthophoria with fewer exophoria and relatively fewer esophoria than either of the other instruments.

Test (8) Acuity OD — Near

The AO instrument showed generally lower visual acuities than the AFVT.

Test (9) Acuity OS — Near

The results are similar to test 8.

Test (10) Prism Divergence at Near

The AO instrument only was used for this test, and it compared very closely with the phorometer. There was no significant deviation.

This data was not analyzed in such a manner as to show if the visual acuity on the AO instrument became progressively poorer due to wearing of the film during use.

OBSERVATIONS MADE BY EXAMINER

In general, the AO machine has the advantages of having all tests on one film. The disadvantages are that it takes longer to run, the letters on the film are not as clear as on the slides. The film for the phoria has a confusing light spot in the area covered by the testing design. The AFVT machine conversely has the disadvantage of having to change slides on the drum for certain tests. Its advantages are that it is faster to use, easier to adjust, and its impressions on the slide are more clear than on the film.

·It is suggested that some device be adapted to each machine to hold head in one position. Perhaps a chin rest or a more satisfactory brow rest. As it is, if patient moves his head so that he relatively increased his upward gaze, the exophoria will increase and if he moves so relative downward gaze increased, his exophoria will decrease. Also, such a device would help insure that the patient gazes through the center of the lenses, thus preventing him from increasing his V.A. by decreasing his spherical abberation by looking through periphery of lenses.

It is further suggested that if one of these are to be used for mass visual screening that a pseudo isochromatic color vision testing target be included. Also that in the prism divergence test, the rotary prism should be colored light pink so that when image breaks, patient will see pink image on the right. This would confirm that divergence was tested and prevent the inexperienced operator from using prism base out instead of base in.

CONCLUSION

The data collected here, suggests that the AO machine is more time-consuming and more complicated for the lay operator, and compares less favorably with the phorometer and wall chart than does the AFVT machine.

Neither machine shows as high a range of visual acuity as does the wall chart and phorometer. The target for lateral phoria for near is poor and leads to unreliability in the AO.

The AFVT machine is not as complete in that all tests are not carried on the drum.

REPORT ON 100 CASES

Inked Numbers in Each Column Show Total.

% Over or Under The "Normal" Range.

#1 = Wall Chart, A-O 1930 Phorometer

#2 = A-O Vision Tester

#3 = B & L Orthorator

Outline = "Normal" Range

NUMERICAL SCORE SYSTEM

COMPARISON OF VISUAL ACUITY SCORES OBTAINED WITH ARMED FORCES WALL CHART AND WITH VISION TESTER PROPOSED BY AMERICAN OPTICAL COMPANY

A. Morris
F. L. Dimmick
B. W. Wild
U.S.N. Medical Research Laboratory
New London, Connecticut

INTRODUCTION

A Working Group was established by the Armed Forces-NRC Vision Committee for the purpose of evaluating the Armed Forces Vision Tester proposed by the American Optical Company. U.S.N. Medical Research Laboratory at the Submarine Base, New London, Connecticut, was given the specific assignment of testing the far visual acuity, monocular and binocular, of approximately 125 men with the Armed Forces Wall Chart and the AO Vision Tester in that order. In addition to the assignment we also made measurements of near acuity and of interpupillary distance.

MATERIALS AND METHODS

An unselected group of 126 candidates for the U.S. Naval Submarine School were tested by the staff of the Vision Branch of MRL according to the plan presented in Table 1. For the far test we used

Table 1

PLAN OF THE TESTING PROGRAM

Acuity Test	Distance	Brightness ft-L
Wall charts		
Far	20 ft.	13
Near	13 in.	17
American Optical Instrument		
Far	26 ft.	12
Near	13 in.	12

For the far test we used the Armed Forces Wall Chart in an alley which met the standards recommended in "Manual of Instructions for Testing Visual Acuity" Army-Navy-NRC Vision Committee, Oct. 1, 1947. The near test was a reproduction of a Snellen chart reduced photographically to give the required angular sizes at 13 inches (devised at MRL by CDR Dean Farnsworth). The tests were administered in the order listed above and each was given monocularly, right, left, and binocularly. Specific descriptions of each of these tests and the scoring systems used are presented in Table 2.

Since the lines of letters on the charts do not progress in equal size steps, do not contain equal numbers of items, and are not given the same code number designations, the scores must be reduced to equivalent decimal or fractional values for computation.

Table 2

DESCRIPTION OF TESTS AND SCORING SYSTEMS

ACUITY		TESTS								
		ARMED FORCES WALL CHART			NEAR WALL CHART			AMERICAN OPTICAL VISION TESTER		
Decimal[+]	Fraction	Line Number	Items per Line	Errors*	Line Number	Items per Line	Errors*	Line Number	Items per Line	Errors*
0.05	20/400							1	3	1
0.1	20/200	I	2	0				2	10	3
0.2	20/100	II	4	1				3	10	3
0.3	20/70	III & IV	10	3	1	3	1	4	10	3
0.4	20/50	V & VI, 1, 2	10 ea	3	2	4	1	5	10	3
0.5	20/40	3	8	2	3	5	1	6	10	3
0.6	20/33									
0.7	20/30	4	10	3	4	6	1	7	10	3
0.8	20/25	5	10	3	5	7	2	8	10	3
0.9	20/22									
1.0	20/20	6, 7, 8, 9	10 ea	3	6	8	2	9	10	3
1.1	20/18									
1.2	20/17							10	10	3
1.3	20/15	10	10	3	7	8	2	11	10	3
1.4	20/14									
1.5	20/13				8	8	2			
1.6	20/12.5									
1.7	20/12							12	10	3
1.8	20/11.1									
1.9	20/10.5									
2.0	20/10	11, A	10 ea	3	9	8	2			

+ Reciprocal minutes visual angle.
* Number of errors permitted for line credit.

RESULTS

Table 3 presents the frequency distribution of far monocular acuity scores (126 men or 252 eyes) measured by the Armed Forces Wall Chart.

The mean interpupillary distance for the group is 65.1 mm. with a standard deviation of 2.8 mm. According to specifications for the AO machine its optical system is designed to allow for IPDs ranging from 55 to 75 mm.

Scattergrams of all the data comparing wall chart with AO instrument acuity scores are presented in the appendix. Table 4 gives means, standard deviations, and correlation coefficients for these data.

Table 3

FREQUENCY DISTRIBUTION OF FAR
MONOCULAR ACUITY SCORES

Armed Forces Wall Chart Line #	Decimal Acuity	Frequency
I	0.1	0
II	0.2	2
III & IV	0.3	7
V, VI, 1, 2	0.4	6
3	0.5	5
-	0.6	-
4	0.7	10
5	0.8	14
-	0.9	-
6, 7, 8, 9	1.0	103
-	1.1	-
-	1.2	-
10	1.3	103
-	1.4	-
-	1.5	-
-	1.6	-
-	1.7	-
-	1.8	-
-	1.9	-
11, A	2.0	2

Table 4

SUMMARY OF VISUAL ACUITY SCORES

Acuity Tests	Wall Chart Mean	o	AO Vision Tester Mean	o	"r"
Far					
Right	0.96	0.16	0.94	0.13	.71
Left	1.07	0.29	0.90	0.27	.71
Binocular	1.23	0.31	1.03	0.27	.77
Near					
Right	1.29	0.31	0.91	0.15	.43
Left	1.23	0.34	0.91	0.15	.53
Binocular	1.41	0.31	1.19	0.20	.60

Group analysis of the data as presented in Table 4 is not the most accurate comparison when the frequency distribution of the population is considered, see Table 3. Therefore, we analyzed the AO far acuity scores for the groups of subjects making 1.0 decimal acuity and for the group making 1.3 on the Armed Forces Wall Chart. Table 5 shows the frequencies, means, and standard deviations for each of these two groups.

Table 5

FREQUENCY DISTRIBUTIONS OF AO VISION TESTER SCORES
FOR SUBJECTS MAKING 1.0 AND 1.3 ON ARMED FORCES
WALL CHART

American Optical Decimal Acuity	Armed Forces Far Wall Chart 1.0		1.3	
	Right Eye	Left Eye	Right Eye	Left Eye
0.4	1	0	1	0
0.5	4	2	2	0
0.6	-	-	-	-
0.7	5	4	1	1
0.8	21	15	6	6
0.9	-	-	-	-
1.0	21	20	26	19
1.1	-	-	-	-
1.2	4	6	13	14
1.3	0	0	2	11
1.4	-	-	-	-
1.5	-	-	-	-
1.6	-	-	-	-
1.7	0	0	0	1
Mean	0.866	0.915	1.002	1.102
SD	.79	.74	.66	.56
N	56	47	51	52

Physical measurements of letter size: The acuity score values for the tests are based upon the information furnished with the instrument and charts. Because there was a difference of considerable magnitude between the scores with the instrument and those with the wall chart, we made our own measurements of letter sizes. The wall chart letters were found to be very close to stated values. Such is not the case with the AO letters. The test targets in the AO Vision Tester are on 35 mm. film strip. This film was placed under a traveling microscope and measurements of over-all letter sizes were made on a sample of the lines. In Far Test 3, Left Eye, line 5, all ten letters were measured; in lines 8 and 9 five letters each were measured. In Far Test 4, Right Eye, line 1, all three letters were measured. For any single line the several measurements were averaged and divided by five to give mean stroke width. Stroke width divided by the object distance (furnished by AO, 110 mm.) equals the angular subtense of the letters. In Table 6 the effective image sizes as derived from actual measurements are compared to theoretical values.

DISCUSSION

Any evaluation of the differences between the AO Vision Tester and the Armed Forces Wall Chart must be made with caution inasmuch as the nature of the assignment and the distribution of test scores preclude the use of standard comparison statistics based upon normally distributed data.*

* The t-test, for example, assumes independence of measurements and a normal distribution of scores. Neither of these assumptions has been met in our data in that the assigned testing order was not random and the subjects to be tested had been previously screened. The first factor creates non-independence of measurements, and the second, a skewed distribution. Since the product-moment correlation does not place such stringent requirements upon the data, it has been used with reservations in interpretation.

Table 6

COMPARISON OF THEORETICAL AND MEASURED ACUITY TARGET
VALUES FOR THE AMERICAN OPTICAL VISION TESTER

Theoretical Values			AO	Measured Values		
Acuity		Film Size of Stroke mm.	Line #	Film Size of Stroke mm.	Effective Acuity	
Decimal	Fraction				Decimal	Fraction
.05	20/400	.63989	1	.6256	.0511	20/391.4
.4	20/50	.06086	5	.0806	.397	20/50.4
.8	20/25	.03993	8	.0368	.877	20/22.8
1.0	20/20	.032065	9	.0274	1.190	20/16.8

From Table 3 it can be seen that due to the use of screened population and limited number of scale divisions in the Armed Forces Wall Chart the majority of the scores fall at the two scores, 1.0 and 1.3 decimal acuity. For the most part, this noncontinuous distribution limits statements about the comparison of these two scores. A complete evaluation of the whole test would, of course, necessitate an adequate number of cases at each acuity step. However, for whatever they may mean, means and standard deviations for the 126 subjects were presented in Table 4. The mean wall chart scores are consistently higher than the AO scores and for the far tests there is a relatively high correlation between the two series of scores. More pertinent is the information presented in Table 5. Those subjects making 1.0 decimal acuity on the Armed Forces Wall Chart have mean acuity scores of .866 for right eye and .915 for left. For subjects scoring 1.3 decimal acuity on AF wall chart the mean scores are 1.002 and 1.102.

As previously stated, the size of the score differences led to measurement of the letters of both tests and the AO letters were found to be in error. Measurements presented in Table 6 show critical lines #8 and #9 to be, respectively, .031 and .005 mm. too small, producing more difficult targets which are not .8 and 1.0 reciprocal minutes visual angle but nearer .9 and 1.2, respectively.

Returning to the mean scores for the groups in Table 5, we note that the decimal acuity difference produced by this physical error is in the same direction and is of the same magnitude as the mean score differences. Taking the physical error into account, the group means can be crudely converted as follows:

AF Wall Chart Score Group		Group Mean Scores on AO Vision Tester	
		Standard Scoring	Converted Score if .8 = .9 and 1.0 = 1.2
1.0	R	.866	.966
	L	.915	1.015
1.3	R	1.002	1.202
	L	1.102	1.302

The mean acuity scores from the far tests are now comparable. This indicates that closer tolerances must be required in future instrument specifications. The analysis presented above also suggests that any future evaluation program include a validating instrument of known accuracy and of greater sensitivity than the device to be validated. Validation cannot be expected to produce results of any greater significance than is justified by the experimental design employed.

SUMMARY

The far and near, monocular and binocular acuities of 126 men were measured using the Armed Forces Wall Chart, a near wall chart, and the American Optical Vision Tester. The majority of the scores, and, therefore, the comparison fall upon two lines only, 20/20 and 20/15. The mean acuity scores of the AO vision tester were found to be consistently lower than those of the AF wall chart. Physical measurements of the letter sizes show the AO test items to be too small to a degree that explains the acuity score differences.

For adequate calibration of any similar test it is recommended that an adequate number of cases be collected at each acuity level in the test and that comparison be made with a validating standard of known accuracy and greater sensitivity than the test to be validated.

SCATTERGRAMS OF ACUITY SCORES FOR 126 MEN
American Optical Vision Tester

Armed Forces Wall Chart

RIGHT — FAR

	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
2.0											
1.8							2				
1.6											
1.4											
1.2			1	2	7	26	13	2			
1.0											
0.8			1	4	26	21	4				
0.6			1	5							
0.4		1	2								
0.2		2	5								
0.0		1									

RIGHT — NEAR

	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
2.0											
1.8					1						
1.6											
1.4				1	7	32	14				
1.2					9	23	1	1			
1.0											
0.8					12	8	1				
0.6				1	8	2	3				
0.4					1						
0.2			1								
0.0											

LEFT — FAR

	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
2.0											
1.8											
1.6											
1.4											
1.2				7	19	14	11		1		
1.0											
0.8				2	19	20	6				
0.6			2	4	8	4					
0.4				1	1						
0.2		1	4	1							
0.0		1									

Near WALL CHART

LEFT — NEAR

	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
2.0											
1.8											
1.6											
1.4					3	29	11				
1.2					9	26	2				
1.0											
0.8					9	13	2				
0.6				3	10	3		1			
0.4					1						
0.2			1	1	2						
0.0											

BINOCULAR — FAR

	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
2.0											
1.8					3	4		1			
1.6											
1.4											
1.2				5	17	34	21				
1.0											
0.8				1	12	14	2	1			
0.6			1	3	2						
0.4			1								
0.2		1	3								
0.0											

BINOCULAR — NEAR

	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
2.0											
1.8								7	1		
1.6											
1.4					2	4	24	41			
1.2					1	6	12	5			
1.0											
0.8						6	6	1			
0.6					3	2	2	1			
0.4				1							
0.2			1								
0.0											

TEST-RETEST RELIABILITY OF THE EXPERIMENTAL MODEL OF THE AMERICAN OPTICAL COMPANY ARMED FORCES VISION TESTER

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PURPOSE

This portion of the Vision Tester evaluation study had two purposes:

1. To determine the test-retest reliability of tests of visual acuity, phoria, and depth perception which are incorporated in the experimental model of the American Optical Company Vision Tester (AO) and in the Armed Forces Vision Tester (AFVT).

2. To observe critically the operational performance of each Vision Tester, including malfunctions, ease of administration, and time required for administration.

PROCEDURE

Selection of Subjects. A sample of the rotation and combat personnel being processed through the Personnel Center, Fort Knox, Kentucky, served as subjects for the study. Subjects were selected according to a stratified random sampling technique based on the distribution of Army Classification Battery Aptitude Area I scores (a measure of intelligence or ability to be trained) of Army enlisted personnel. The sample represented as closely as was possible the Army distribution of AGCT scores of Enlisted Men as of 30 June 1952.[1] Most of the subjects were Regular Army men.
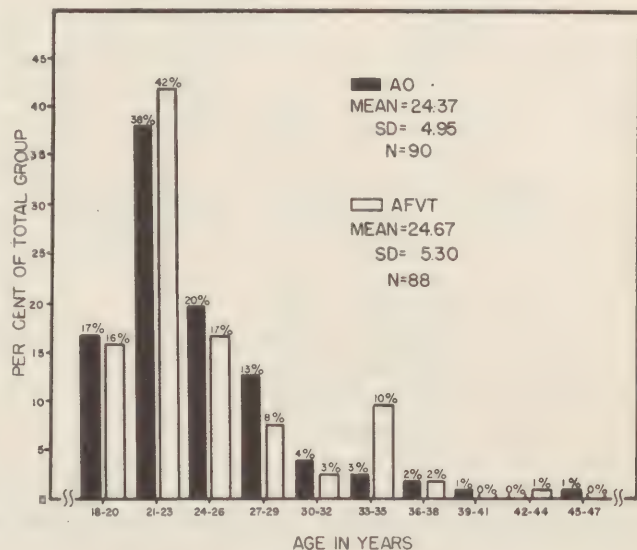

Figure 1

Figure 2

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1. Human Resources Research Office Study No. 17-1: Qualification and Aptitude Testing at Army Induction. Washington: George Washington University, Human Resources Research Office, 10 Mar. 1953.

A total of 178 subjects were tested, 90 on the AO Vision Tester and 88 on the AFVT. The two groups were alike with respect to means and variability values on both Aptitude Area I scores (Figure 1) and age (Figure 2). It is clear that the distributions of these two variables are highly similar for the men tested on each instrument; the small mean differences noted are not statistically significant.

The equating of the two groups of subjects served two purposes, to insure as representative a sample of the Army population as possible and to control factors which might be related to vision test performance. As Table 1 shows, visual skills were not significantly related to Aptitude Area I scores for either group, but were related significantly to ages of subjects in the AFVT group for three tests. The statistically significant relationships give some justification for having equated the groups, but indicate also that any error introduced through not having matched groups would not have been great.

Table 1

PRODUCT-MOMENT CORRELATIONS AND MULTIPLE CORRELATIONS
BETWEEN VISUAL SKILLS AND THE MATCHING VARIABLES OF
APTITUDE AREA I[1] AND AGE[1]

Visual Skill	Subjects Tested on the AO Instrument			Subjects Tested on the AFVT		
	r AAI	r Age	R	r AAI	r Age	R
Far Vertical Phoria	.07	-.14	.14	-.18	-.09	.22
Far Lateral Phoria	.16	-.03	.16	-.03	-.18	.19
Far Acuity—Right	.00	.03	.03	.14	.20	.27[a]
Far Acuity—Left	-.14	-.03	.15	-.03	.36[b]	.36[b]
Far Stereopsis	-.17	.13	.19	.14	.15	.22
Near Vertical Phoria	-.14	.02	.14	.12	.04	.13
Near Lateral Phoria	.16	-.16	.21	-.01	-.22[a]	.22
Near Acuity—Right	.04	.16	.18	.06	.21[a]	.23
Near Acuity—Left	.10	.11	.17	-.07	.15	.16
		N = 90			N = 88	

1. The correlation between Aptitude Area I and Age was .24 for the men tested on the AO instrument, and .16 for the men tested on the AFVT.
[a]Significant beyond the 5 per cent level of confidence.
[b]Significant beyond the 1 per cent level of confidence.

Vision Subtests Used in the Study. One AO instrument and one AFVT instrument were used in the evaluation. Both devices ostensibly measure the same visual skills, which were presented in the following order in both instruments:

1. Far Vertical Phoria
2. Far Lateral Phoria
3. Far Acuity—Right Eye
4. Far Acuity—Left Eye
5. Far Stereopsis

6. Near Vertical Phoria
7. Near Lateral Phoria
8. Near Acuity—Right Eye
9. Near Acuity—Left Eye

Both Vision Testers have alternative and reputedly equivalent tests of far acuity, near acuity, and stereopsis. The malingering devices and the Landolt ring-type acuity tests which can be used with each instrument were not used in this study.

Testing Procedure. Two examiners administered all of the vision tests, changing from one instrument to the other after about every 20 administrations. The standard test

instructions for the two instruments were modified slightly so as to make the two sets of questions as nearly alike as possible for the two instruments. The test instructions used, and the manner in which each test was scored, are given in Appendix A.

Approximately 24 hours after being tested, each subject was tested again on the same instrument by the same examiner. The alternative tests of visual acuity and depth perception in each instrument were used for the retesting of these skills. Subjects were not permitted to wear glasses during any of the vision testing.

RESULTS

Reliability of the Vision Tester Measures. A good test should measure the relative performance of a number of subjects with consistency. The product-moment correlations between the test and retest scores for each instrument are shown in Table 2. In order to test the significance of the differences between the test-retest correlations for each instrument, the correlation coefficients were converted to Fisher z values and a t test made of the differences between the z values.

Table 2

TEST-RETEST RELIABILITY COEFFICIENTS FOR EACH VISUAL SKILL
FOR EACH VISION TESTER

Visual Skill	AO Test-Retest Correlation	AFVT Test-Retest Correlation	t Ratio[1]
Far Vertical Phoria	.55	.88	4.97[c]
Far Lateral Phoria	.71	.81	1.57
Far Acuity—Right	.90	.80	2.42[a]
Far Acuity—Left	.92	.83	2.61[a]
Far Stereopsis	.76	.70	.85
Near Vertical Phoria	.66	.62	.39
Near Lateral Phoria	.76	.77	.13
Near Acuity—Right	.69	.83	2.22[a]
Near Acuity—Left	.66	.90	4.44[c]
	N = 90	N = 88	

1. Correlation coefficients were converted to z values and the significance of differences between z values were computed.
[a] Significant beyond the 5 per cent level of confidence.
[b] Significant beyond the 1 per cent level of confidence.
[c] Significant beyond the 0.1 per cent level of confidence.

Five t ratios are statistically significant beyond the five per cent level of probability. The statistically significant values indicate that the AFVT tests of far vertical phoria and near visual acuity have significantly higher test-retest correlations than the same tests on the AO instrument. Possibly, the AFVT test-retest correlation for far lateral phoria also is higher than that for the AO device. The AO instrument test-retest correlations are higher for the far acuity tests than are the same values for the AFVT. The reliability coefficients for the other visual skills of stereopsis and near phoria are little different for the two instruments.

In summary, the AO device has significantly higher reliability coefficients for two visual skills, and the AFVT has significantly higher values for three, and possibly four, skills.

<u>Stability of the Vision Test Scores</u>. In addition to being able to measure relative differences between individuals consistently, a good test should do so in an absolute manner. In other words, not only should the relative rank of each individual's test and retest scores be the same, but also the test score values should be the same as the retest score values, assuming that there has been no learning of the ability being measured.

In Table 3, comparisons are made between test and retest means and standard deviations for each vision skill for each Vision Tester. Each of the instruments has three visual skills tests which show significant differences between test and retest. For the AO Vision Tester, these are the far visual acuity tests and near visual acuity-left eye; for the AFVT, stereopsis, near vertical phoria, and near acuity-left eye. It will be noted, however, that the t ratios indicating the magnitude of these differences are generally higher for all AO test-retest mean differences, than for the AFVT mean differences.

Table 3

DIFFERENCE BETWEEN TEST AND RETEST MEANS AND VARIANCES OF
EACH VISION SKILL FOR EACH VISION TESTER

Visual Skill	Test		Retest		t Ratio (SD's)	t Ratio (Means)
	Mean	SD[1]	Mean	SD[1]		
			AO			
Far Vertical Phoria	5.39	.93	5.26	.73	2.71[b]	1.56
Far Lateral Phoria	10.49	1.87	10.24	2.21	2.27[a]	1.47
Far Acuity—Right	8.06	2.01	8.38	1.90	1.22	3.46[c]
Far Acuity—Left	8.61	1.83	8.88	1.99	2.00[a]	3.20[b]
Far Stereopsis	2.57	2.14	2.81	2.14	.00	1.58
Near Vertical Phoria	5.14	.88	5.07	.76	1.57	1.07
Near Lateral Phoria	14.30	3.35	14.06	3.06	1.32	1.03
Near Acuity--Right	9.03	1.45	9.20	1.41	.36	1.39
Near Acuity--Left	8.96	1.23	9.22	1.13	1.11	2.58[a]
			AFVT			
Far Vertical Phoria	4.62	1.11	4.61	.99	2.40[a]	.20
Far Lateral Phoria	8.62	2.14	8.51	2.56	2.73[b]	.71
Far Acuity—Right	9.55	1.84	9.58	1.98	1.17	.26
Far Acuity—Left	9.48	2.10	9.72	2.21	.85	1.79
Far Stereopsis	3.00	2.05	3.84	1.86	1.27	5.18[c]
Near Vertical Phoria	4.38	1.14	4.61	1.10	.44	2.31[a]
Near Lateral Phoria	16.01	4.51	16.09	4.33	.60	.25
Near Acuity—Right	9.65	1.41	9.80	1.43	.25	1.65
Near Acuity--Left	9.62	1.67	9.82	1.72	.62	2.45[a]

[1]N-1 was used in the denominator in computing all standard deviations reported.
[a]Significant beyond the 5 per cent level of confidence.
[b]Significant beyond the 1 per cent level of confidence.
[c]Significant beyond the 0.1 per cent level of confidence.

Five of the test and retest standard deviations were significantly different, the far phoria measures for both instruments, and far left eye acuity as measured by the AO. For both instruments, far vertical phoria variability decreased significantly on the retest while far lateral phoria variability increased significantly on the retest; AO left eye far acuity also increased significantly.

To summarize the changes in test and retest scores, the number of visual skills having statistically significant mean differences is the same for both instruments. The AO in-

instrument shows statistically significant gains in far visual acuity for each eye, and in near visual acuity for the left eye. The AFVT shows statistically significant gains in near acuity-left eye and in stereopsis, and a significant change in near vertical phoria scores. Far phoria variability measures increase significantly for both instruments on retest.

Although the magnitude of these acuity changes is statistically significant, the amount of change actually is slight (visual acuity, for example, showing a maximum gain of .32 instrument score units, which when converted to Snellen notation, is a change from 20/25 to 20/23).

Observations of the Operational Performance of the Two Instruments. Both instruments require about the same amount of time to test an individual. It was not possible to administer the nine tests to more than six subjects per hour on either device.

AO Vision Tester.
1. The right eye occluder handle is impeded by the upright support when the instrument body is raised to test tall examinees.

2. The viewing box does not "click" into place for the near tests, and unless it is pressed firmly down, the near test lens system will not have moved into proper position.

3. The headrest (curved headrest) twists, often not positioning the subject's head properly.

4. Targets become blurred as the eye moves from the optical center of the lens toward the periphery. This might have implications for persons who have extreme interpupillary distances.

5. With the curved headrest on it, the instrument will not fit into its case.

AFVT
1. The position of the occluder is such that one frequently brushes the examinee's face with the fingers in turning the occluder.

2. Acuity test Lines 10, 11, and 12 sometimes are difficult for the subject to locate—he reads Line 7 when 10 is called for, presumably because the number designating Line 10 is located at the right of Line 7. This difficulty was not apparent for AO acuity slides on which the numbers designating Lines 10, 11, and 12 are at the right end of the respective lines.

Both AO and AFVT
1. Alternate acuity test letters appear to be darker and more easily read than does the first line of letters at each level of difficulty.

2. There are illumination differences between the two instruments, the brightness of the AO stereopsis test being 14.9 foot-lamberts, and B&L stereopsis test being 10.4 foot-lamberts as measured by the MacBeth Illuminometer (but it will be noted in Table 3 that acuity values for the AO instrument are always lower than those for the AFVT).

3. The sequence of test items on the stereopsis test is confusing to the subject in that he attempts to read across the chart rather than down. The slide would be more easily read if it were arranged as if one were reading a printed page: AB .
                                                                                        CD
                                                                                        EF
4. The subject is confused by the three groups of five circles for each stereopsis test item. It is suggested that the stereopsis demonstrator also have three rows of circles arranged in the same fashion as the subject sees them in the instrument.

5. The open space between the upper part of the instrument body and the viewing box of both instruments admits room lighting which is disturbing to the subject.

Instructions and Scoring Keys
1. The AO vertical phoria test instructions about "walking down the steps and stepping on the dotted line" frequently are misunderstood and therefore make for some error in measurement. The AFVT test question, "With what step is the dotted line nearest level?" may be more easily understood, but it also can be improved upon.

2. It is suggested that the scoring keys would be used more easily and with less error if the "Right Eye" and "Left Eye" columns of letters were reversed because the manual directs that the right eye be tested first, and then the left eye; or the order of testing the two eyes might be changed.

3. The lack of numbers to help identify the circles on the stereopsis test target slows the administration of this test. Numbering the columns of circles on the slide, or numbering the circles on the stereopsis demonstrator, would help the subject to communicate his response to the examiner.

4. Page 13 of the manual for the AFVT is in error in the interpretation of Tests 2 and 7: The words "esophoria" and "exophoria" should be interchanged wherever they appear.

General Comment on Acuity Scoring. It is recognized that the method of visual acuity scoring, which allows the subject to miscall three or fewer letters in a line without failing that line, probably is a very reliable method for determining the level of visual acuity. Such a method is difficult for the examiner to use, however. Unless the examiner is especially attentive while administering the acuity test, he may forget the number of letters miscalled in a line and erroneously give credit for the line. An easier procedure, from the standpoint of the examiner, would be to allow fewer errors before failure, or to require, as a basis of failure, that a subject miscall a certain number of successive letters on a line. While such a scoring system might result in a lower reliability coefficient when tests are administered under the rigor of an experiment, it is felt that the simpler scoring technique would result in operationally higher reliability when fatigue of the examiner is taken into account.

Test Differences Between Examiners. The two persons administering the vision test in the study were competent and highly motivated examiners, more highly trained in test administration than one normally would expect to find among enlisted personnel engaged in administering vision tests. Despite the testing capabilities of the two examiners, there are differences in the mean test results obtained by each examiner, as shown in Tables 4 and 5. There were statistically significant differences between examiners in near acuity-right eye on the AO instrument, and in near acuity-left eye on the AFVT. In variability, there were three significant differences between examiners on the AO, and two on the AFVT.

Differences in reliability obtained by each examiner are shown in Table 5. These results have occurred for several reasons: differences between subjects tested by each examiner, differences between examiners in their test administration, or an interaction between instruments and examiners. These differences do not vitiate the evaluation study; they do suggest that test instructions and procedures be made so foolproof that such differences cannot appear.

SUMMARY AND CONCLUSIONS

Two groups of enlisted men were subjects for the reliability study, 90 men being tested on one instrument, and 88 on the other. The two groups of men were comparable with respect to age and intelligence. Approximately 24 hours after initial testing, each

man was retested on the same Vision Tester by the same examiner. The Vision Testers were then compared on the basis of the difference between test and retest correlation values for the nine visual skills measured by each instrument, and the amount of change in mean test and retest scores for each instrument.

The results of the study may be summarized as follows:

1. In general, the Armed Forces Vision Tester measures the visual skills with more consistency than does the experimental American Optical Company instrument.

2. The two instruments are essentially the same in the ease of their administration and in the amount of testing time required per subject.

Table 4

DIFFERENCES IN MEAN VISION TEST RESULTS OBTAINED BY
TWO EXAMINERS ON THE FIRST TESTING

Visual Skill	Examiner I		Examiner II		F Ratio (Variances)	t Ratio (Means)
	Mean	SD	Mean	SD		
AO						
Far Vertical Phoria	5.53	1.10	5.26	.74	2.23[b]	1.35
Far Lateral Phoria	10.30	2.13	10.66	1.59	1.80	.90
Far Acuity—Right	7.88	2.05	8.21	1.98	1.07	.78
Far Acuity—Left	8.51	1.89	8.70	1.79	1.12	.49
Far Stereopsis	2.12	2.27	2.98	1.94	1.37	1.94
Near Vertical Phoria	5.09	.89	5.19	.88	1.04	.53
Near Lateral Phoria	13.93	3.55	14.64	3.14	1.28	1.00
Near Acuity—Right	8.67	1.77	9.36	.99	3.21[b]	2.23[a]
Near Acuity—Left	8.84	1.54	9.06	.84	3.33[b]	.81
	N = 43		N = 47			
AFVT						
Far Vertical Phoria	4.62	1.17	4.63	1.05	1.26	.02
Far Lateral Phoria	8.71	1.91	8.53	2.37	1.54	.38
Far Acuity—Right	9.56	1.67	9.53	2.03	1.47	.05
Far Acuity—Left	9.36	2.25	9.60	1.95	1.32	.55
Far Stereopsis	2.89	2.12	3.12	1.99	1.14	.52
Near Vertical Phoria	4.60	1.27	4.14	.94	1.82	1.92
Near Lateral Phoria	16.71	4.38	15.28	4.58	1.09	1.50
Near Acuity—Right	9.47	1.62	9.84	1.15	1.97[a]	1.23
Near Acuity—Left	9.27	1.92	10.00	1.27	2.29[b]	2.09[a]
	N = 45		N = 43			

[a]Significant beyond the 5 per cent level of confidence.
[b]Significant beyond the 1 per cent level of confidence.
[c]Significant beyond the 0.1 per cent level of confidence.

Table 5

DIFFERENCES IN TEST-RETEST RELIABILITY COEFFICIENTS OBTAINED
BY EACH EXAMINER ON EACH VISION TESTER

Visual Skill	Examiner I Test-Retest Correlation	Examiner II Test-Retest Correlation	t Ratio[1]
	AO		
Far Vertical Phoria	.61	.46	.95
Far Lateral Phoria	.66	.81	1.55
Far Acuity—Right	.90	.90	.00
Far Acuity—Left	.91	.93	.59
Far Stereopsis	.74	.84	1.23
Near Vertical Phoria	.58	.80	2.00
Near Lateral Phoria	.79	.73	.64
Near Acuity—Right	.68	.62	.45
Near Acuity—Left	.65	.67	.14
	N = 43	N = 47	
	AFVT		
Far Vertical Phoria	.90	.85	.95
Far Lateral Phoria	.87	.78	1.27
Far Acuity—Right	.72	.90	2.55[a]
Far Acuity—Left	.80	.87	1.05
Far Stereopsis	.71	.71	.00
Near Vertical Phoria	.91	.25	5.77[c]
Near Lateral Phoria	.81	.76	.59
Near Acuity—Right	.86	.77	1.23
Near Acuity—Left	.96	.78	4.09[c]
	N = 45	N = 43	

[1]Correlation coefficients were converted to z values and the significance of differences between z values was computed.
[a]Significant beyond the 5 per cent level of confidence.
[b]Significant beyond the 1 per cent level of confidence.
[c]Significant beyond the 0.1 per cent level of confidence.

Appendix A

TEST QUESTIONS AND METHODS OF SCORING USED FOR
AO and AFVT

A. Standard Distance Tests—Viewing box in the "up" position.
  1. Far Vertical Phoria—Both occluders in the "up" position for AO; occluder in the mid position for AFVT.

     Do you see a white dotted line? Do you see a row of numbered stairsteps? If you were walking down the steps, at what number would you step on the dotted line?

     Score is number given. If below Step 1, record 0; if above Step 9, record 10. If both steps and dotted line cannot be seen at the same time, record X.

  2. Far Lateral Phoria—Both occluders in the "up" position for AO; occluder in the mid position for AFVT.

     To which number does the arrow point? Score is number given.

     If arrow points to left of 1, score 0; if to right of 21, score 22. If arrow and numbered dots cannot be seen at the same time, record X.

  3. Far Letter Acuity (Small Letters)—Occluder before eye not being tested. Test first right, and then left eye.

     Right eye—Read the letters on Line 5 at the top of the chart. Look at the smaller lines of letters on the left and the still smaller ones on the right. What is the smallest line you can read? Score is the number of the smallest line read with not more than three errors.

     Left eye—What is the smallest line you can read? Score in the same manner as for right eye.

  4. Far Letter Acuity (Large Letters)—Occluder before eye not being tested. Use test only if each or one eye cannot be scored in Test 3. Score is the number of the smallest line read with not more than three errors, except for the first line, in which there can be no more than one error.

  5. Fusion and Depth Perception—Both occluders in the "up" position for AO; occluder in the mid position for AFVT.

     Fusion Test—Do you see a large square containing letters and circles? To the left of the square what do you see? Describe it. Subject should see an arrow with a single shaft passing through a circle. Occlude right eye. What do you see now? Subject should see only tail of arrow. Move both occluders to the "up" position for AO; move occluder to mid position for AFVT.

     Depth Test—Will you look in this direction? This next test will show groups of circles like this. Show demonstrator. Do you see that this circle is closer to you than the others? Look into the instrument again. In Group A, look at the top row of circles. Which circle is closer to you? Clues may be given for Group A. If Group B is failed, repeat Groups A and B. Score is 0 if Group B is failed the second time. Otherwise, record the better score of the last group in which no errors are made; i.e., record B as 1, C as 2, D as 3, E as 4, and F as 5.

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B. Standard Near Tests—With subject's head away from the instrument, the viewing box is lowered to the "down" position and subject is instructed: Now place your head in the same position.

6. Near Vertical Phoria—Both occluders in the "up" position for AO; occluder in the mid position for AFVT.

   If you were walking down the steps, at what number would you step on the dotted line? Score as in Test 1.

7. Near Lateral Phoria—Both occluders in the "up" position for AO; occluder in the mid position for AFVT.

   For AO—To which number does the V (or the A) point? Record score as described for Test 2, placing a V or an A in front of the number, whichever is appropriate.

   For AFVT—To which number does the arrow point? Record score as described for Test 2.

   (Note: To make AO near lateral phoria "V" scores equivalent to "A" scores, add a constant of 12 to the "V" score.)

8. Near Letter Acuity (Small Letters)—Occluder before eye not being tested. Test first right, and then left eye. Test and score as in Test 3.

9. Near Letter Acuity (Large Letters)—Occluder before eye not being tested. Use test only if each eye or one eye cannot be scored in Test 8. Test and score as in Test 4.

Appendix B

FREQUENCY DISTRIBUTION OF THE VISUAL SKILLS ON TEST AND RETEST FOR AO and AFVT

Far Vertical Phoria

Instrument and Administration	0	1	2	3	4	5	6	7	8	9	Mean	SD
AO Test	–	–	–	–	9	50	23	4	3	1	5.39	.93
AO Retest	–	–	–	–	8	57	20	4	1	–	5.26	.73
AFVT Test	–	2	–	3	35	38	8	–	–	2	4.62	1.11
AFVT Retest	–	2	–	3	31	45	5	–	2	–	4.61	.99

Far Lateral Phoria

Instrument and Administration	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Mean	SD
AO Test	–	–	–	–	–	2	1	4	5	13	11	26	19	7	2	–	–	–	–	–	–	–	–	10.49	1.87
AO Retest	–	1	–	–	–	4	1	3	5	9	22	17	18	8	2	–	–	–	–	–	–	–	–	10.24	2.21
AFVT Test	–	2	1	2	–	2	–	3	21	39	6	8	2	1	1	–	–	1	–	–	–	–	–	8.62	2.14
AFVT Retest	1	3	1	1	–	1	4	4	16	37	9	6	2	2	–	–	–	–	–	–	–	–	–	8.51	2.56

Far Acuity—Right

Instrument and Administration	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean	SD
AO Test	–	1	2	1	2	4	7	5	20	30	16	2	–	8.06	2.01
AO Retest	–	–	2	–	3	2	9	5	12	31	22	4	–	8.38	1.90
AFVT Test	–	–	2	–	1	–	3	1	8	21	21	28	3	9.55	1.84
AFVT Retest	–	–	–	3	–	2	1	4	10	12	20	30	6	9.58	1.98

Far Acuity—Left

Instrument and Administration	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean	SD
AO Test	–	–	–	3	2	2	5	3	14	33	20	8	–	8.61	1.83
AO Retest	–	–	2	1	1	2	5	5	9	25	24	16	–	8.88	1.99
AFVT Test	–	1	1	1	1	1	3	2	6	19	18	32	3	9.48	2.10
AFVT Retest	–	–	2	2	1	–	3	1	8	11	15	37	8	9.72	2.21

Appendix B (Cont'd)

Far Stereopsis

	0	1	2	3	4	5	Mean	SD
AO Test	28	8	9	5	10	30	2.57	2.14
AO Retest	24	10	6	6	8	36	2.81	2.14
AFVT Test	21	6	6	7	15	33	3.00	2.05
AFVT Retest	12	4	4	3	8	57	3.84	1.86

Near Vertical Phoria

	0	1	2	3	4	5	6	7	8	9	Mean	SD
AO Test	–	–	–	1	14	54	16	3	1	1	5.14	.88
AO Retest	–	–	–	1	14	58	13	3	1	–	5.07	.76
AFVT Test	–	3	2	5	38	32	7	–	–	1	4.38	1.14
AFVT Retest	–	1	2	5	30	39	9	–	1	1	4.61	1.10

Near Lateral Phoria

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Mean	SD
AO Test	–	–	–	2	–	1	1	2	–	3	1	–	3	1	42	9	4	5	2	3	7	4	2	–	2	–	–	–	–	–	–	–	14.30	3.35
AO Retest	–	–	–	–	–	–	2	3	1	–	4	1	3	4	46	8	5	11	3	12	5	1	5	2	2	–	–	–	–	–	–	–	14.06	3.06
AFVT Test	–	1	1	–	–	1	2	–	2	3	9	3	5	3	9	11	3	12	5	8	9	6	8	2	2	–	–	–	–	–	–	1	16.01	4.51
AFVT Retest	–	1	–	–	–	2	–	1	4	6	9	10	8	6	9	3	10	8	6	8	4	4	1	–	1	–	–	–	–	–	–	–	16.09	4.33

Near Acuity—Right

	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean	SD
AO Test	–	–	–	–	2	4	1	2	4	43	28	6	–	9.03	1.45
AO Retest	–	–	–	–	1	2	3	1	7	38	26	12	–	9.20	1.41
AFVT Test	–	–	–	–	1	1	2	3	10	18	25	28	1	9.65	1.41
AFVT Retest	–	–	–	–	1	–	2	2	8	19	23	29	4	9.80	1.43

Near Acuity—Left

	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean	SD
AO Test	–	–	–	–	2	1	–	6	7	49	21	4	–	8.96	1.23
AO Retest	–	–	–	–	–	2	1	2	10	37	31	7	–	9.22	1.13
AFVT Test	–	1	–	–	1	1	1	2	7	24	17	33	1	9.62	1.67
AFVT Retest	–	1	–	–	–	2	1	2	8	14	23	31	6	9.82	1.72

A COMPARISON OF THE SCORES MADE BY THE SAME SUBJECTS ON THE AO EXPERIMENTAL VISION TESTER AND THE AFVT

Introduction

The data reported upon in this Appendix were collected at Camp Carson, Colorado, in conjunction with a study not directly related to the purpose described in the body of the report. These results are being included as an Appendix to the report because they furnish comparative information about the AO and AFVT instruments when both were used to test the same subjects.

Purpose

To compare AO Vision Tester and AFVT measures taken on the same subjects.

Subjects

The 136 men tested in this study were Army enlisted men who had just completed their Basic Training. The average age of the group was about 21 years; 110 of the subjects were Caucasian, 24 Negroid, and 2 American Indian.

Procedure

Prior to being tested on the two Vision Testers, each man was tested on four other vision tests: the Bausch and Lomb Ortho-Rater, the Navy Interpupillometer Mark 1, the Three-Dimension Company Projection Stereopsis Test-Slides PV12 and PV13, and the Wirt Stereotest. These four tests were administered in a systematic order so that each of the four preceded or followed any one of the other three an equal number of times. Thus, any effect which any other instrument might have had upon Vision Tester scores should have been the same for both Vision Testers. Testing on the two Vision Testers also was alternated, so that half of the subject group were tested on the AO first, and half were tested on the AFVT first.

Two examiners administered all Vision Tester examinations, changing from one instrument to the other after about every 25 administrations. The same examiner never tested the same subject on both of the Vision Testers.

Test instructions and scoring methods used are given in Appendix A. The subjects wore the visual correction which they customarily wore during their normal outdoor activities; only eight wore glasses for the testing.

Results

A comparison of the means and variabilities of the nine visual skills as measured by each Vision Tester is shown in Table 1. All t ratios testing the significance of differences between mean values (with the exception of far stereopsis) are significant beyond the one per cent level of confidence; the mean differences for stereopsis are significant at the five per cent level. Differences in visual acuity are most marked, values about one instrument score unit higher being achieved on the AFVT.

The relative size of the mean far and near lateral phoria scores for the two Vision Testers are not consistent. The far lateral phoria mean is significantly larger for the AO than for the AFVT, but the near lateral phoria mean is significantly lower for the AO than

for the AFVT. This inconsistency indicates an inequality of the phoria slide calibration—slide focal length combination in the two instruments.

It will be noticed, also, that near lateral phoria variability for the two instruments differs significantly as shown by the t value of 2.86, variability on this test being lower for the AO Vision Tester. It is possible that the two sets of "fusion dots" on the AO slide (below the V and above the A), as compared to the one set of dots below the arrow on the AFVT slide, may account for the greater stability of the AO measure. This enforced stability may hamper the measurement of phoria, however, inasmuch as fusion will not permit excursion of the eyes (and consequently of the V and A pointers), and a true measure of the phoria may not be obtained. Near left eye acuity measures also differ significantly in variability.

Table C-1

VISION TESTER SCORES ON THE SAME SUBJECTS WITH TESTS OF
SIGNIFICANCE AND CORRELATION BETWEEN THE TWO INSTRUMENTS

Visual Skill	AO		AFVT		t Ratio (SD's)	t Ratio (Means)	r
	Mean	SD	Mean	SD			
Far Vertical Phoria	4.82	.79	4.43	.74	1.00	4.88[c]	.63
Far Lateral Phoria	10.65	2.04	9.46	1.97	.54	8.52[c]	.67
Far Acuity—Right	9.23	1.30	10.43	1.45	1.88	12.85[c]	.69
Far Acuity—Left	9.62	1.48	10.34	1.46	.29	9.60[c]	.82
Far Stereopsis	3.40	1.97	3.66	1.92	.50	2.52[a]	.81
Near Vertical Phoria	4.66	.87	4.40	.85	.33	3.65[c]	.52
Near Lateral Phoria	14.38	3.72	15.76	4.53	2.86[b]	4.32[c]	.61
Near Acuity—Right	9.50	1.11	10.35	1.20	1.29	12.11[c]	.75
Near Acuity—Left	9.37	1.16	10.26	1.36	2.71[b]	12.48[c]	.79

N = 136

[a]Significant beyond the 5 per cent level of confidence.
[b]Significant beyond the 1 per cent level of confidence.
[c]Significant beyond the 0.1 per cent level of confidence.

Table C-1 also includes the product-moment correlations between the same visual skill scores measured by each Vision Tester. In a sense, these correlations might be interpreted as the reliability coefficients of the tests—the tests were the same, but were administered in different instruments by different examiners. In general, then, these correlations should represent the lower limits of reliability of each of the visual skills measured by either of the two Vision Testers. One of the tests, far stereopsis, has a correlation coefficient exceeding the test-retest reliabilities reported in the body of the report.

Half of the subjects were tested on the AO instrument first, and half on the AFVT first. It is of interest to note the differences in test results for these two subgroups. These results are summarized in Table C-2, for the far tests only. For the AO instrument scores, those subjects who were tested on the AO second (hence on the AFVT first) had significantly larger acuity and stereopsis test scores than those subjects who were tested on the AO first. For the AFVT, those subjects who were tested on the AFVT second (hence on the AO first) had no statistically significant differences in acuity and stereopsis test scores from those subjects tested first on the AFVT. To summarize Table C-2, AO acuity and stereopsis test scores are significantly larger for those subjects who were tested on the AFVT instrument first; AFVT acuity and stereopsis scores are not significantly different for those subjects who were tested on the AO instrument first. These

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results could mean that the subjects tested first on each instrument were not the same with respect to their visual skills or they could be interpreted that previous experience on one instrument enhances performance on the other. The latter interpretation seems to be a better one.

Table C-2

VISION TESTER SCORES SHOWING THE EFFECT OF EXPERIENCE OF
ONE VISION TESTER UPON PERFORMANCE ON THE OTHER
(for distance tests only)

| | Vision Tester Scores | | | | | |
| | Tested First on AO | | Tested Second on AO | | | |
	Mean	SD	Mean	SD	F Ratio	t Ratio
Far Vertical Phoria	4.82	.69	4.82	.88	1.63	.00
Far Lateral Phoria	10.81	2.08	10.49	2.00	1.08	.92
Far Acuity—Right	8.96	1.42	9.50	1.13	1.59	2.48[a]
Far Acuity—Left	9.25	1.61	9.99	1.25	1.65	2.98[b]
Far Stereopsis	2.88	2.03	3.93	1.78	1.30	3.18[b]
	N = 68		N = 68			
	Tested First on AFVT		Tested Second on AFVT			
	Mean	SD	Mean	SD	F Ratio	t Ratio
Far Vertical Phoria	4.40	.76	4.47	.72	1.10	.58
Far Lateral Phoria	9.19	1.78	9.74	2.11	1.41	1.62
Far Acuity—Right	10.44	1.37	10.41	1.53	1.24	.12
Far Acuity—Left	10.29	1.41	10.38	1.52	1.15	.35
Far Stereopsis	3.98	1.73	3.34	2.06	1.41	1.98
	N = 68		N = 68			

[a]Significant beyond the 5 per cent level of confidence.
[b]Significant beyond the 1 per cent level of confidence.
[c]Significant beyond the 0.1 per cent level of confidence.

A statistical test of the vision scores also was made to determine if there were differences in the scores of the two examiners (Table C-3). There were no significant differences in the mean scores obtained by either examiner on either instrument, although there were variability differences between examiners in three instances.

Summary and Conclusions

Vision test scores were obtained on 136 Army enlisted men using both the AO and AFVT instruments. Half of the subjects were tested on the AO instrument first, and half were tested on the AFVT first. Two examiners administered all tests changing from one instrument to the other after about every 26 test administrations.

The results of the testing demonstrated that:

1. The two Vision Testers differ significantly in the scores they furnish for each of the nine visual skills measured. Visual acuity scores differ most markedly.

2. AO Vision Tester far acuity and stereopsis scores are influenced significantly by previous testing on the AFVT instrument, but the AFVT scores are not so influenced by prior testing on the AO device.

3. There were no differences in the mean vision test scores obtained by each examiner.

Table C-3

DIFFERENCES IN MEAN VISION TEST RESULTS OBTAINED
BY TWO EXAMINERS
(for distance tests only)

Visual Skill	Examiner II		Examiner III		F Ratio (Variances)	t Ratio (Means)
	Mean	SD	Mean	SD		
			AO			
Far Vertical Phoria	4.92	.68	4.73	.94	1.90[a]	1.15
Far Lateral Phoria	10.46	2.25	10.91	2.21	1.04	.99
Far Acuity—Right	9.37	1.48	9.16	1.19	1.56	.76
Far Acuity—Left	9.79	1.32	9.53	1.69	1.64	.84
Far Stereopsis	3.42	2.02	3.33	1.94	1.08	.22
	N = 52			N = 45		
			AFVT			
Far Vertical Phoria	4.36	.88	4.52	.61	2.10[b]	1.07
Far Lateral Phoria	9.36	2.18	9.37	2.11	1.06	.02
Far Acuity—Right	10.58	1.14	10.52	1.60	1.98[a]	.20
Far Acuity—Left	10.33	1.68	10.50	1.28	1.73	.55
Far Stereopsis	3.71	1.85	3.75	1.90	1.05	.10
	N = 45			N = 52		

[a]Significant beyond the 5 per cent level of confidence.
[b]Significant beyond the 1 per cent level of confidence.

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CLINICAL EVALUATION OF THE AMERICAN OPTICAL COMPANY'S
1245 MG EXPERIMENTAL ARMED SERVICES VISION TESTER

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OBJECTIVE

To compare the performance of the American Optical Company's proposed Armed Services Vision Tester with measurements of visual function obtained in the standard 20 foot eye lane and on the standard Armed Forces Machine Vision Tester. Comparisons of measurements of the following visual functions were made: visual acuity, monocular, near and distant; visual acuity, binocular, distant; visual acuity, monocular, distant with illiterate chart; vertical and lateral heterophoria, near and distant; fusion; and stereopsis.

METHOD

One hundred subjects were tested. These subjects included personnel of the School of Aviation Medicine; pilot cadet candidates; flying personnel undergoing routine annual physical examinations; and some Aviation Medical Examiner students. Twelve wore glasses and were tested both with and without correction.

Testing was administered by three persons: Captain Philip T. Shahan, M/Sgt Lynn Daniels and M/Sgt Joseph Kowalski, all of the Department of Ophthalmology, School of Aviation Medicine. After these three men had become proficient in administering each of the three batteries of tests, they were rotated among the three testing stations at random, so that any effect produced by minor differences in operating technique would be cancelled out.

The three batteries of tests consisted of the following:

1. American Optical Company 1245 MG Experimental Armed Services Vision Tester: Referred to hereafter as "AO".

   Slide 1: Vertical heterophoria, distant
   Slide 2: Lateral heterophoria, distant
   Slides 3 and 4: Monocular visual acuity, right and left eye, distant
   Slide 5: Fusion and stereopsis, distant
   Slide 6: Vertical heterophoria, near
   Slide 7: Lateral heterophoria, near
   Slides 8 and 9: Monocular visual acuity, right and left, near
   Slide 10: Monocular visual acuity, right and left, illiterate, distant
   Slide 11: Binocular visual acuity, distant

The remaining slides furnished with the instrument were not used in this study: these were 3A, 4A, 5A, 12, 13, 14, and 15. Consequently, it must be emphasized that our results do not reflect the performance of these alternate or optional slides.

2. <u>20 Foot Eye Lane</u>: Referred to herafter as "Lane".

   a. Visual acuity, monocular, distant: tested with the "Armed Forces Visual Acuity Tests," a chart adopted by the Armed Forces-NRC Vision Committee.

   b. Visual acuity, binocular, distant: same chart.

   c. Heterophoria, distant: white Maddox rod, Risley rotary prism and muscle light at 20 feet, performed in lighted lane. No cover was used.

   d. Heterophoria, near: white Maddox rod and ophthalmoscope bulb at 13 inches, performed in lighted lane, without a cover.

Fusion, depth perception and near visual acuity were not tested in the eye lane.

3. <u>The Armed Forces Machine Vision Tester</u> (officially designated as Vision Test Apparatus, Near and Distant),   referred to hereafter as AFMVT.

   Slide 1: Vertical heterophoria, distant
   Slide 2: Lateral heterophoria, distant
   Slides 3 and 4: Monocular visual acuity, distant
   Slide 5: Fusion and Stereopsis, distant
   Slide 6: Vertical heterophoria, near
   Slide 7: Lateral heterophoria, near
   Slides 8 and 9: Monocular visual acuity, near

No other slides of this machine were used. Comparisons between this machine and the experimental machine are based, therefore, on these specific numbered slides and none other.

The 100 subjects were tested by these three methods in random order. By this procedure, approximately one-half the subjects received the AO machine before the AFMVT, while the other one-half received the machines in reverse order. The tests in the U.C. Lane were carried out as a first procedure in about one-third of the cases; were intermediate between the machines one-third of the time; and were the last procedure one-third of the time.

Scoring of the various tests and analyses of the data were carried out as described below under "RESULTS".

RESULTS

1. Vertical heterophoria, distant

   a. Measurements were recorded in prism diopters of right or left hyperphoria. Inspection of the results obtained by all three methods (AO, AFMVT, Maddox Rod at 20 feet) showed that there were not enough cases with hyperphoria to warrant statistical evaluation of the group. Inspection showed also that all three tests gave essentially identical scores for each individual, with no individual showing greater than one-half prism diopter difference among the three methods.

   b. Conclusion: Proposed AO Tester measures distant hyperphoria clinically the same as a Maddox Rod at 20 feet or the AFMVT.

2. Vertical heterophoria, near

a. Same recording as for distant vertical phorias. Data studied again by simple inspection. Results same as for distant vertical heterophoria.

b. Conclusion: Proposed AO Tester measures near hyperphoria clinically the same as a Maddox Rod at 13 inches or the AFMVT.

3. Lateral heterophoria, distant

a. Measurements recorded in prism diopters of esophoria or exophoria. In the case of the two machines, the subjects were instructed to regard the dotted line and the arrow, with neither eye occluded, and to report the final position of the arrow after any "drift" had settled down. A similar technique was used with the Maddox Rod.

Three comparisons were made: AO machine with Maddox Rod; AO with AFMVT; AFMVT with Maddox Rod. In order to arrive at these comparisons, the number of prism diopters difference between the two methods was recorded for each individual. For instance, if on the proposed machine a measurement of 6 p.d. of esophoria was obtained, and in the eye lane a measurement of 3 p.d. esophoria was obtained, the comparison of the machine with the lane would be +3. The plus sign indicates that the machine gives 3 p.d. greater heterophoria, in the direction of esophoria, than the Maddox Rod at 20 feet. The differences were totalled, and the mean difference calculated.

b. Results of these three comparisons are detailed in Table 1, and in Figures IA and IB.

Table 1

DISTANT LATERAL HETEROPHORIA

	AO with Lane	AO with AFMVT	AFMVT with Lane
Total Number	106	106	105
Sum, all differences	$- 39^{\Delta}$	-110^{Δ}	$+ 69^{\Delta}$
Mean difference	$- 0.37^{\Delta}$	$- 1.03^{\Delta}$	$+ 0.66^{\Delta}$
No. + differences	33	16	50
Sum + differences	$+ 58^{\Delta}$	$+ 29^{\Delta}$	$+118^{\Delta}$
Range + differences	0 to $+4^{\Delta}$	0 to $+6^{\Delta}$	0 to $+8$
No. - differences	54	63	32
Sum - differences	$- 97^{\Delta}$	-139^{Δ}	$- 49^{\Delta}$
Range - differences	0 to -5^{Δ}	0 to -8^{Δ}	0 to -4^{Δ}
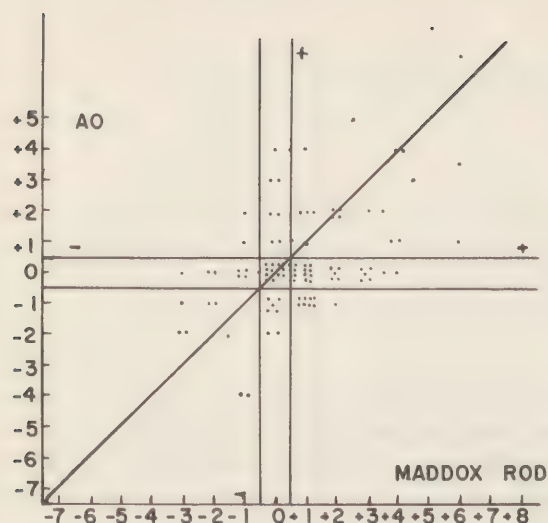
Fig. IA – Far lateral heterophoria comparison
of AO with Maddox Rod at 20 ft.
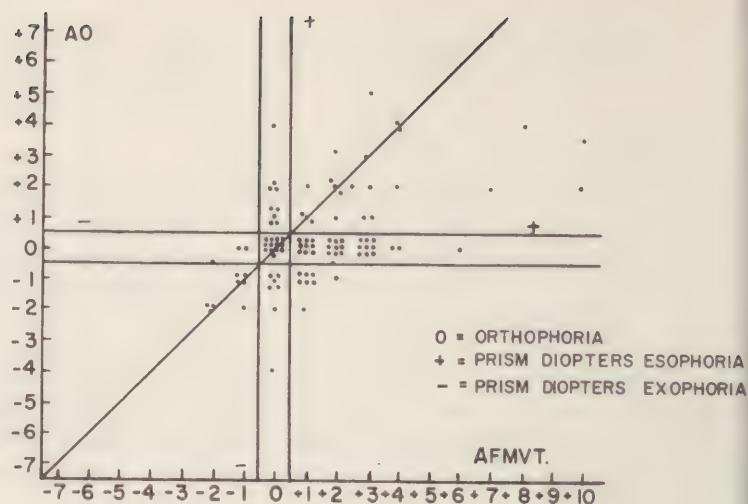
Fig. IB – Far lateral heterophoria comparison
of AO with AFMVT.

Table 2

NEAR LATERAL HETEROPHORIA

	AO with Lane	AO with AFMVT	AFMVT with Lane
Total Number	105	106	106
Sum, all differences	$+157^\Delta$	-97^Δ	$+295^\Delta$
Mean of differences	$+1.5^\Delta$	-0.91^Δ	$+2.8^\Delta$
No. + differences	59	37	70
Sum + differences	$+306^\Delta$	$+135^\Delta$	$+368^\Delta$
Range + differences	0 to $+19^\Delta$	0 to $+12^\Delta$	0 to $+24^\Delta$
No. - differences	38	53	30
Sum - differences	-149^Δ	-231^Δ	-73^Δ
Range - differences	0 to -12^Δ	0 to -11^Δ	0 to -22^Δ

Briefly, the comparisons of lateral heterophoria measurements were as follow:

(1) AO with Lane: AO gave mean lateral distant heterophoria 1/3 prism diopter farther in the direction of exophoria than the mean obtained with the Maddox Rod at 20 feet.

(2) AO with AFMVT: AO gave mean lateral heterophoria 1 prism diopter farther toward exophoria than the mean obtained on the AFMVT.

(3) AFMVT with Lane: AFMVT gave mean lateral heterophoria 2/3 prism diopter farther toward esophoria than the Maddox Rod at 20 feet.

c. Conclusion: Measurement of distant lateral heterophoria by the AO proposed machine gives scores averaging approximately the same as those obtained in the eye lane but 1 prism diopter different in the direction of exophoria from the AFMVT.

4. Lateral heterophoria, near

a. Measurements were recorded in prism diopters of esophoria or exophoria. A difference between the two machines' target requires description. The AO machine's left eye target employs two letters, a "V" above the dotted line and an "A" below the dotted line. In orthophoria the "V" points to the dot numbered 1 as seen by the right eye, and the "A" to the dot numbered 13. In esophoria, both letters move to the left, which makes the "V" go off the scale. Some slight delay was encountered with some subjects in explaining this feature of the targets to them, but in no case did the examiners fail to get a stable reading. "Floating" of the letters was not a problem. The presence of two letters, one near the end of the dotted line, tended to prevent floating, by offering greater fusion stimulus. The AFMVT target employs a single arrow for the left eye, which stands above the dotted line seen by the right eye. In several cases this arrow appeared to "float" up and down the scale, so that the examiners were forced to record the mid-position between the extremes of floating.

b. As in the case of far lateral heterophoria, three comparisons were made: AO v. Lane; AO v. AFMVT; and AFMVT v. Lane. The comparisons are detailed in Table 2. Briefly, the near lateral heterophoria measurements compared as follow: (mean differences of 106 measurements).

(1) AO with Lane: AO gave 1.5 p.d. more esophoria than Lane.
(2) AO with AFMVT: AO gave 1 p.d. less esophoria than AFMVT.
(3) AFMVT with Lane: AFMVT gave 2.8 more esophoria than Lane.

The scattered distribution of scores for each of these comparisons is shown in Figures IIA, IIB, and IIC. Inspection of these Figures shows that a large proportion of the points deviates widely from the diagonal line drawn through points of equal measurement. This scatter is so large that it is doubtful whether any valid comparisons can be made of the clinical performance of any two of these three methods. Clinically, comparison of the mean near lateral heterophoria scores indicates that on the average the AO machine gives slightly more esophoria than the Maddox Rod, and slightly less esophoria than the AFMVT. In individual cases, one or the other machine indicated differences as high as 22 prism diopters greater or less esophoria than the Maddox Rod. It is therefore doubtful whether the mean score differences resulting from variations in apparatus construction are as important as factors within the individual being tested.
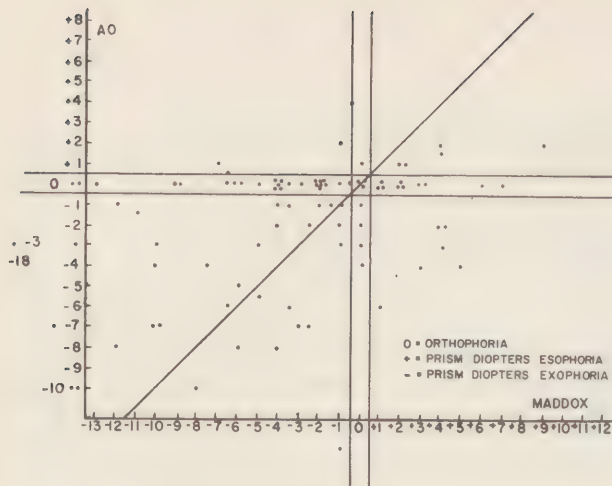
Fig. IIA - Near lateral heterophoria AO compared with Maddox Rod at 13 inches.
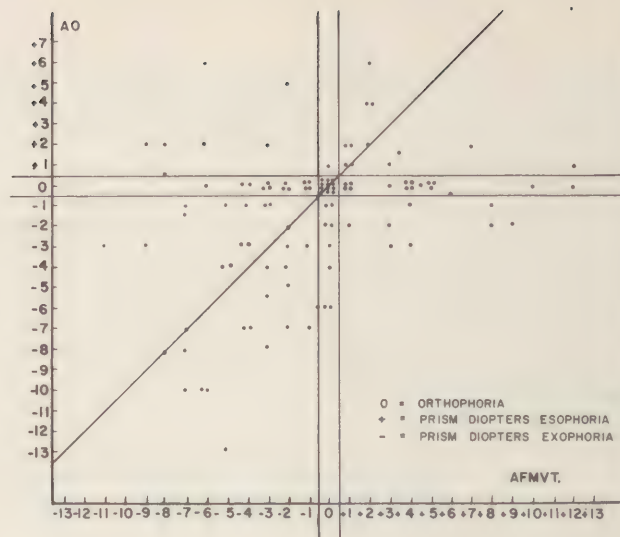
Fig. IIB - Near lateral heterophoria AO compared with AFMVT.
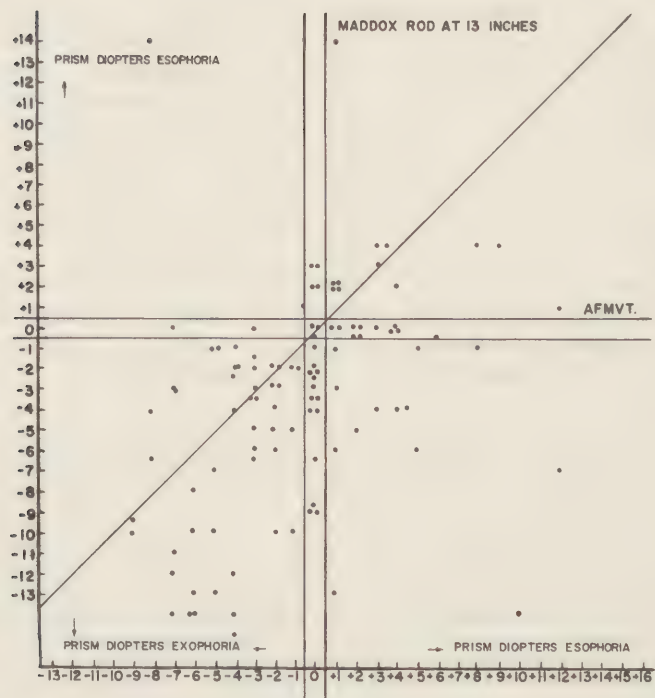
Fig. IIC - Near lateral heterophoria AFMVT compared with Maddox Rod.

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5. Visual acuity, monocular, distant

Scores were recorded as Snellen fractions, e.g., 20/20, 20/25, etc. Comparison between tests was made by recording the number of whole acuity lines difference between the scores of the tests under comparison. For instance, in comparing AO with Lane, if AO acuity was 20/30 and Lane acuity 20/20, the difference is -2. The -2 here signifies that the AO score was 2 acuity lines worse than the Lane. Mean differences were calculated for the three comparisons. The distribution of comparative scores was plotted. The scatter of the distribution is shown by Figures IIIA and IIIB. There was no difference between the comparative scores of the right and left eyes, so the monocular data are all plotted together. Briefly summarized, the mean differences between the three comparisons (AO v. Lane; AO v. AFMVT; and AFMVT v. Lane) were as follow: (228 measurements).

a. AO with Lane: One whole acuity line poorer visual acuity recorded by the AO than with the wall chart.

b. AO with AFMVT: One and one-half acuity lines poorer visual acuity recorded by AO than by AFMVT.

c. AFMVT with Lane: One-half acuity line better visual acuity recorded by AFMVT than with wall chart. This difference is due entirely to the fact that the AFMVT (as well as AO) has a 20/17 acuity line between 20/20 and 20/15, where the wall chart has none. Since a large proportion of the 100 persons tested had visual acuity of 20/20 or better on the wall chart, the inclusion of a 20/17 line in the machine would make the machine's mean acuity score seem better than the chart.

d. The clinical significance of these comparisons is that the AO experimental machine records distant acuity significantly worse than either the wall chart or the AFMVT. In terms of pilot cadet candidates requiring acuity of 20/20 without correction of each eye, this difference in acuity recording would eliminate about one-fourth the candidates now accepted. Inspection of Figure IIIA shows that the AO gives acuity of less than 20/20 in 49 instances (out of a total of 224 measurements) wherein the wall chart recorded 20/20 or better.

e. Conclusion: The AO experimental model gives a monocular distant visual acuity score one whole acuity line worse than the score recorded by either the wall chart or the AFMVT. This is a serious and unacceptable defect in a device to be used for selection of Air Force personnel.

6. Visual acuity, binocular, distant

Same method of recording. Only one comparison made: AO with Lane. 101 binocular measurements were made. The mean difference between the AO and Lane was one-half acuity line poorer acuity recorded by the AO than with the wall chart. Distribution of comparative scores is shown in Figure IV.

7. Visual acuity, monocular, near

Same method of recording. Measurements were made only on the two machines. Comparison of 224 monocular measurements gave a mean difference of 2/3 acuity line between the machines. AO mean acuity score was 2/3 line poorer than AFMVT. Distribution of comparative scores is shown in Figure V.

8. Visual acuity, monocular, distant (Using AO illiterate chart)

Eighty-six comparisons were made between AO letter acuity and AO illiterate acuity. The two charts performed comparably in recording acuity, although exact comparison is impossible because of the few acuity steps on the illiterate chart. Distribution of comparative scores is shown in Figure VI.

43
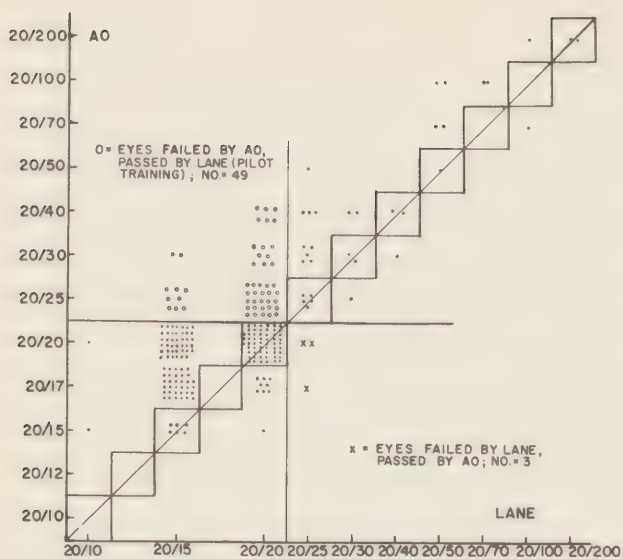
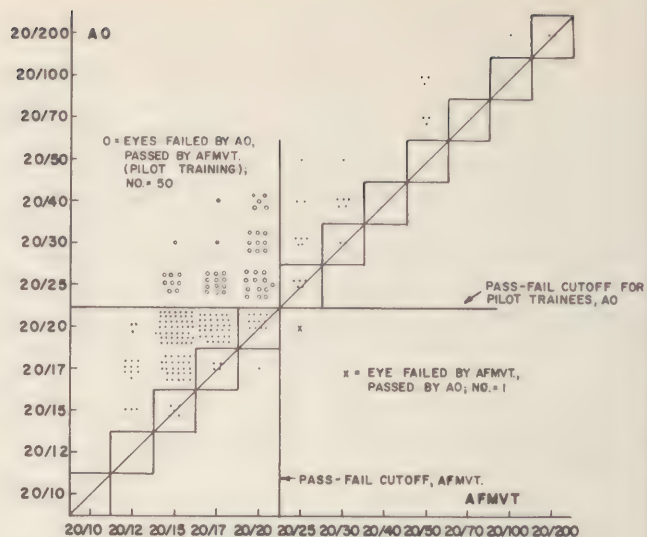Fig. IIIA – Distant monocular acuity AO
compared with lane.

Fig. IIIB – Distant monocular acuity AO
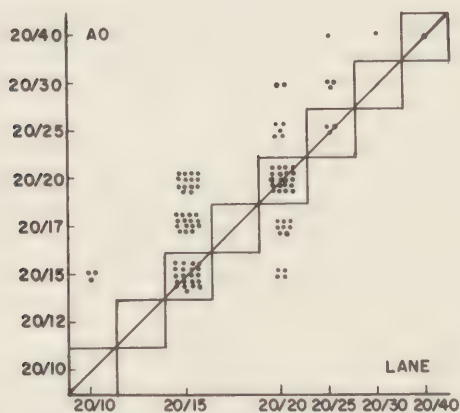compared with AFMVT.

Fig. IV – Binocular distant acuity AO
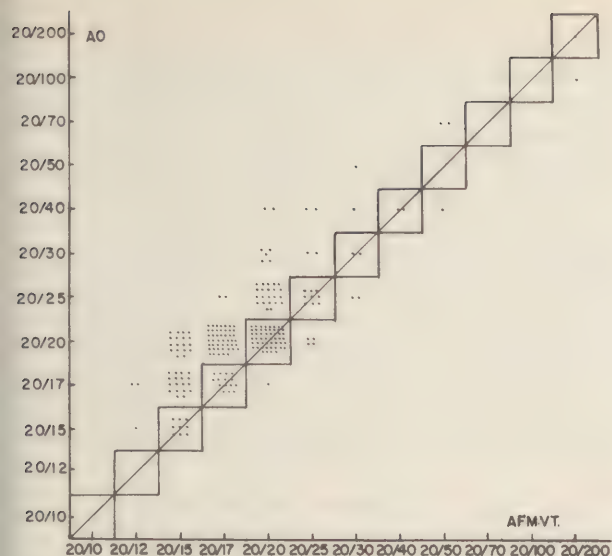compared with lane.

44

Fig. V - Near monocular acuity AO compared with AFMVT.
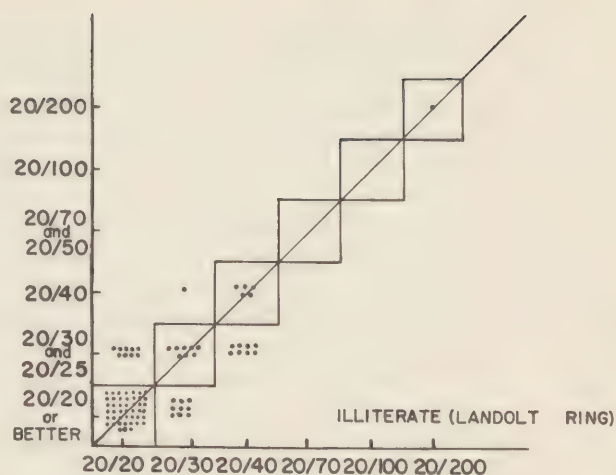

Fig. VI - Distant acuity, monocular AO illiterate compared with AO letters.

Table 3

FUSION AND STEREOPSIS

Total number of Tests: 107

Fusion (arrow on Slide 5, both machines)

Passed both machines	105
Failed both machines	1
Failed AO, passed AFMVT	1
Total:	107

Stereopsis (circles on Slide 5, both machines)

Passed both machines	87
Failed both machines	5
Failed AO, passed AFMVT	14 *
Failed AFMVT, passed AO	1
Total:	107

* Of these 14, 8 were tested first on the AO machine, while 6 were tested first on the AFMVT. These latter 6 represent a real difference between the two machines, inasmuch as they were failures after the technique of the test had been learned by the individuals being tested.

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9. Fusion and Stereopsis

    a. 107 comparative measurements were made on the two machines. Results are detailed in Table 3. The AFMVT passed 14 individuals who failed AO, whereas the AO passed only 1 individual who failed AFMFT. For the Air Force, this represents a net loss of 13 individuals as pilot candidates, if AO were the official standard. Of the 14 passed by AFMVT and failed by AO, 6 AO failures were by persons who had first encountered the AFMVT and passed it. These 6 "trained subject" failures show that the AO stereopsis test is slightly, but quite definitely, more difficult to stereo than is the AFMVT. The number of persons failing either test is too few, however, to make this an important conclusion. It was the impression of all three of the testing personnel that the performance of the two tests was about equal and that both tests required a considerable degree of patience in administration. The stereopsis test consumed about one-half of the total testing time of the machine on which it was first encountered by the subject.

    b. Conclusion: AO stereopsis test slightly more difficult to pass than AFMVT. Both tests were time-consuming to an equal degree.

DISCUSSION

From the above results it is evident that the AO machine does not measure visual acuity or stereopsis as satisfactorily for Air Force purposes as do the two standard tests with which it was compared. The AO machine probably measures heterophoria with equal clinical validity, but with somewhat different scores. Some discussion of the possible reasons for these results is in order:

1. Visual Acuity - Several possible reasons for the relatively poor scores obtained on AO suggest themselves on simple inspection of the acuity charts.

    a. Aberrations in the Optical System - A movement of the eye toward the periphery of the viewing aperture reduces acuity by about one line. This can be avoided by proper centering of the subject's eye, but it is hard to control when testing monocularly.

    b. Poor Printing of the Test Letters - As compared with AFMVT, the letters at each acuity level appear to be fainter, thinner, and less sharply printed. The AO letters simply do not look as black and heavy as those of AFMVT, so that the smaller AO acuity lines appear to fade into the illuminated background. By contrast, even the smallest letters of AFMVT stand out as distinct marks, even though too small for recognition.

    c. Higher Contrast Between Letters and Background - This high contrast may account for some of the apparent fading out of the smaller letters, in addition to poor printing of the letters.

It is the opinion of this investigator that the acuity slides can be improved by proper attention to detail on the part of the manufacturer.

2. Fusion and Stereopsis - The fusion arrow in both machines was passed by all but two of the subjects. The difference in performance of the subjects on the Stereopsis targets is a small one in this study. Comment on this small difference will be left to another investigator in this project whose specific task was evaluation of the Stereopsis test.

3. Far Lateral Heterophoria - Sloan and Rowland[1] have shown that several standard clinical tests for heterophoria, among which was the static Maddox Rod test employed in this study, correlated about as well with each other as with the Ortho-Rater (present AFMVT heterophoria tests) and a former AO instrument named the Sight Screener. The present study leads to similar conclusions with respect to comparison of Maddox Rod, AO, and AFMVT. Inspection of Figure IA shows that the AO machine gives many more measurements of orthophoria than does the Maddox Rod, probably because of greater stimuli to fusion in the machine's targets. The AO likewise gives a greater number of orthophoric scores than does AFMVT, indicating again greater fusion stimuli in AO than in AFMVT. Assuming that all three methods measure the same visual function, it is clear that the AO machine's target #2 "stabilizes" or "fixes" the accommodation-convergence mechanism in such a way that a score of orthophoria is more commonly encountered than with the other two methods. This greater stabilization of AO as compared with AFMVT is probably due to the smaller size of the arrows, dots, and numerals on Slide #2 of AO. Whether this tendency toward orthophoria represents a more valid or a less valid measurement of static muscle balance than scores obtained by the other two methods cannot be concluded from these data. It can be stated, however, that none of the three methods gave scores to any individual outside the current pass-fail limits for pilot candidates, with the exception of the two subjects who had heterotropia. For the Air Force, therefore, the AO machine performs as well as, but no better than, the Maddox Rod and the AFMVT.

4. Near Lateral Heterophoria - The same "stabilization" tendency of the AO targets as compared with AFMVT and Maddox Rod is even more evident here. The distinguishing feature of the AO target is the presence of 2 letters and 6 dots in the plate presented to the left eye. These letters prevent "floating," by increasing fusional stimuli, but at the same time introduce some confusion, which demands a longer testing time than the other two methods. The AFMVT's arrow, while certainly not confusing, floated for some individuals to such an extent that a stable reading was not obtained. Some individuals solved the floating dilemma by a convergence spasm, others by complete relaxation of convergence, both tricks accomplishing a fixing of the arrow at one or the other end of the line of dots. The Maddox Rod test at 13 inches was similarly characterized by instability in some individuals.

Since the Air Force at present has no standards for near phorias, for the reason that what is measured by all three of these tests probably does not relate to ability to perform visual tasks, no statement should be made here as to the relative value, to the Air Force, of these three tests. It is the opinion of the investigator that the AO target gives more stable scores and is, therefore, clinically a "better" test of near lateral heterophoria than the Maddox Rod or the AFMVT target. It must be emphasized, however, that this opinion refers only to the ease of getting a score, and not to the validity of any relationship between the score and ability to perform tasks at near. The latter relationship is undetermined.

SUMMARY AND CONCLUSIONS

1. The AO 1245 MG Experimental Armed Services Vision Tester was compared with the official Armed Forces Machine Vision Tester and with the standard eye lane. Several visual functions of 100 subjects were measured by these three techniques. The measurements were tabulated, mean differences among the three methods were calculated, and the scattering of comparison scores was plotted.

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[1] Sloan, Louise L. and Rowland, William M., Comparison of Ortho-Rater and Sight Screener Tests of Heterophoria with Standard Clinical Tests. Final Report of Project NR 141-526, The Johns Hopkins Univ.

2. Results of these comparison studies were:

   a. Visual acuity monocular distant: AO scores averaged one whole acuity line worse than the 20 foot eye lane, and one and one-half acuity lines worse than AFMVT. This difference makes these plates (Nos. 3 and 4) of AO unacceptable to the Air Force, because they will fail one-fourth of the eyes passed by the other two tests for pilot candidacy.

   b. Visual acuity binocular distant: AO one-half acuity line worse than eye lane.

   c. Visual acuity, illiterate plate, distant: AO illiterate plate No. 10 (Landolt ring) clinically equivalent to AO letter plates (Nos. 3 and 4).

   d. Visual acuity, monocular near: AO mean score two-thirds line worse than AFMVT. Near acuity was not tested in the eye lane.

   e. Vertical heterophoria, near and distant: No clinically significant differences between AO, Maddox Rod, and AFMVT.

   f. Lateral heterophoria, distant: AO mean score differs from mean score of Maddox Rod by less than one-half prism diopter. AO mean score is one diopter farther toward esophoria than AFMVT. AO has greater fusional stability and gives a larger proportion of orthophoria scores than either AFMVT or Maddox Rod. All three tests passed or failed the same individuals, on the basis of Air Force pilot candidate criteria.

   g. Lateral heterophoria, near: AO 1.5 prism diopters farther toward esophoria than Maddox Rod. AO 1 prism diopter farther toward exophoria than AFMVT. Scatter of both comparisons very large. Fusional stability of AO target considerably greater than AFMVT or Maddox Rod. The AO plate was easier to administer than AFMVT and Maddox Rod because of absence of "floating" of the AO target seen by the left eye.

   h. Fusion and Stereopsis: AO fusion arrow gives scores identical with AFMVT arrow. AO stereopsis circle target fails more persons than does AFMVT, using the Air Force pass-fail cut-off between D and E.

3. Conclusions:

   a. AO machine unacceptable to Air Force with respect to measures of visual acuity, both distant and near, monocular and binocular.

   b. AO test of stereopsis less satisfactory than AFMVT.

   c. AO tests of vertical heterophoria equal to AFMVT and eye lane.

   d. AO tests of lateral heterophoria somewhat more "stable" than AFMVT and Maddox Rod, but equal in performance with respect to Air Force pass-fail criteria for pilot candidates. AO near lateral heterophoria targets considered easier to administer than AFMVT and Maddox Rod.

APPENDIX

Enumeration of Mechanical and Operational Defects

Although not called for in this study, because the instrument under consideration was a handmade experimental model, some comment must be made regarding mechanical and operational difficulties encountered.

1. Mechanical Difficulties:

    a. The viewing box release button and locking mechanism for changing from distant to near jammed repeatedly and was repaired each time with some difficulty. This mechanical arrangement for raising and lowering the viewing box needs to be sturdier, more accurate and easier to operate than it is, and probably should be redesigned on a different mechanical principle.

    b. The target housing thumb screw was more difficult to manage than a snap-lock would have been.

    c. The rubber foot plates fell out easily.

    d. The film cannister fell apart in operation, which made the film-wiping edge of the cannister lose contact with the film. As a result, lint gathered on the film strip.

2. Operational Difficulties:

    a. Film advance knob and rewind crank required rather delicate handling and adjustment, in order to avoid (1) tearing the film, (2) running the film off the roll, and (3) faulty positioning of the targets. This necessary delicacy of handling is undesirable for a test to be administered by enlisted personnel.

    b. The illuminated "Target Position Indicator" seemed inconveniently placed, requiring that the operator look from the side of the instrument. The window seemed smaller than necessary.

    c. The film was inadvertently rewound past plate one and off the reel. This required reattaching the end of the strip and realigning the sprochet tooth with the arrow. Some lock is needed to prevent the rewind operation from turning the film off the spool.

    d. The anti-malingering prism adjusting levers should be placed out of sight of the patient.

    e. The few persons wearing bifocals were unable to line up the near targets accurately, because of the degree of head tilt required.

3. General Comment:

    The small size of everything about this instrument requires more exacting adjustments and more delicate handling than seems desirable. It would seem to be an ideal instrument for screening of patients in a physician's civilian office, but for routine use in armed forces examining centers, more rugged, less exacting mechanics would be desirable.

COMPARISON OF THE AMERICAN OPTICAL VISION TESTER AND THE ARMED FORCES FAR VISUAL ACUITY TEST

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INTRODUCTION

This study of visual acuity scores compared the American Optical Vision Tester using Sloan Plates (AO) with a wall chart, the Armed Forces Far Visual Acuity Test (AFFVAT).

A. Sample

The examinees were 100 enlisted men from Fort Meade, Maryland. The mean age was 22.8 years with approximately two-thirds of the group between 19.2 years and 26.2 years.

B. Method

Each examinee was tested with each eye (uncorrected) on both AO and AFFVAT. The order of presentation was: AO-left eye, AO-right eye, AFFVAT-left eye, AFFVAT-right eye.

Correlation coefficients were computed between scores on AO and on AFFVAT. The score used for each man was the total number of letters read correctly (including letters on the line in which four or more errors were made -- the failure line).

For purposes of comparing distributions of acuity ratings, scoring was by interpolation on the basis of the proportion of letters read correctly on the failure line. All Snellen fraction scores so obtained were then converted to decimal equivalents by computing the reciprocal of the Snellen fraction. The mean group score for each eye on each instrument was obtained by averaging the decimal equivalents and then reconverting to Snellen fractions.

RESULTS

Correlation Coefficients Between AO and AFFVAT Shown in Table 1

Table 1

CORRELATIONS BETWEEN AO AND AFFVAT BASED ON TOTAL NUMBER OF LETTERS READ CORRECTLY

(N = 100)

Type of Observation	Coefficient
Left Eye	.89
Right Eye	.90
Left and Right Eye (N = 200 eyes)	.89

Average performance on AO and on AFFVAT is compared in Table 2.

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Table 2

MEAN SNELLEN FRACTION AND DECIMAL ACUITY SCORES
FOR AO AND AFFVAT

(N = 100)

Type of Observation	Mean Snellen Rating	Mean Decimal Score
AO-Left Eye	20/30.6	1.53
AO-Right Eye	20/28.2	1.41
AFFVAT-Left Eye	20/21.6	1.08
AFFVAT-Right Eye	20/22.8	1.14

The distributions of acuity ratings by Snellen fractions are given in Table 3 and in Figure 1. The frequency distributions in Figure 1, rather than standard deviations, are presented to show dispersion since the deviation statistic appears to be less easily interpreted because of the skewness of the distributions. Approximately 5% of the group in each case failed to read the largest line with either eye on either target.

Table 3

DISTRIBUTIONS OF ACUITY RATINGS BY SNELLEN FRACTION

Snellen Fraction	AO Left	AO Right	AFFVAT Left	AFFVAT Right
20/400	5	4	NA *	NA
20/200	2	2	6	4
20/100	1	1	1	0
20/70	3	0	4	5
20/50	5	4	4	1
20/40	6	7	2	4
20/30	5	10	4	5
20/25	11	8	1	7
20/20	17	18	22	18
20/17	28	26	NA	NA
20/15	17	20	24	25
20/12	0	0	NA	NA
20/10	NA	NA	32	32
	100	100	100	100

* Not Applicable
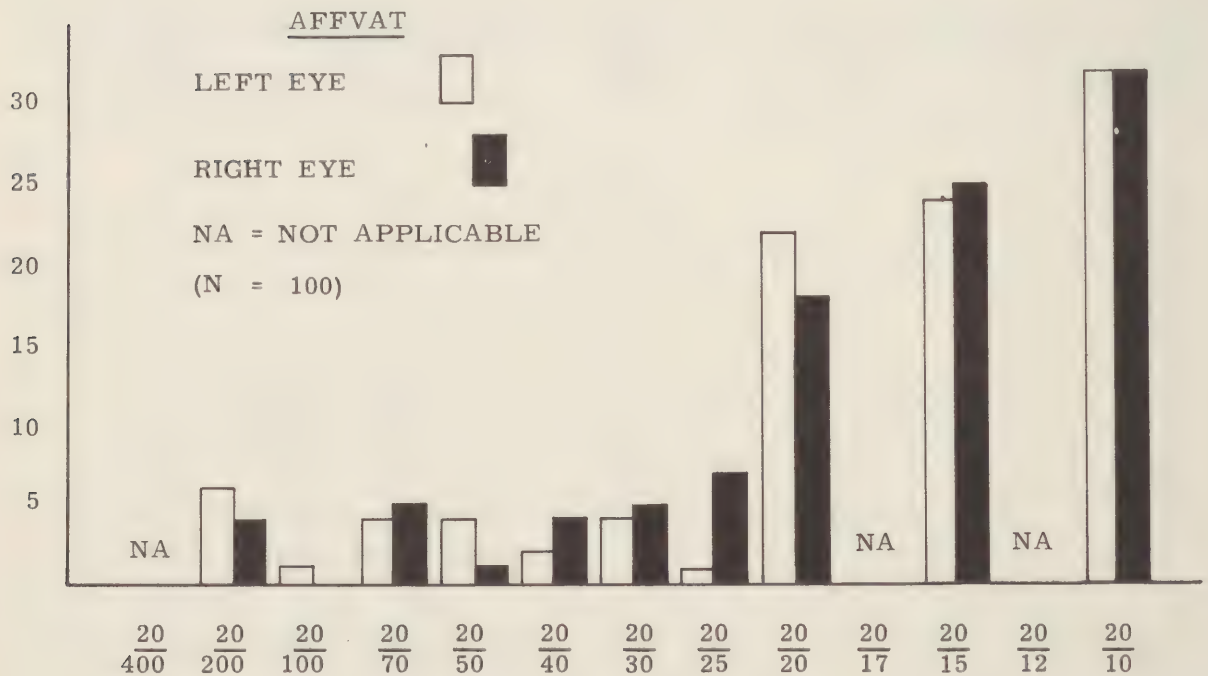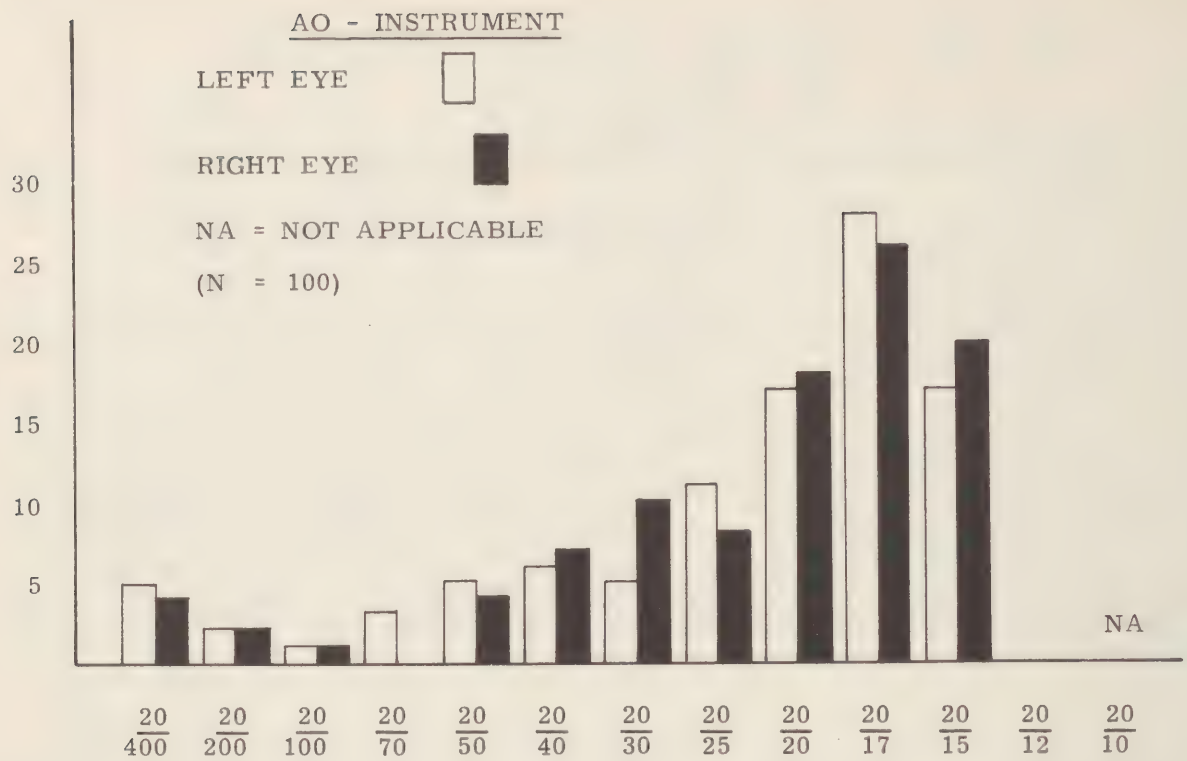
Figure 1. Distributions of acuity ratings on American Optical Instrument (AO) and on Armed Forces Far Visual Acuity Test (AFFVAT).

DISCUSSION

The primary objective of this study was to determine the correlation between AO and AFFVAT; to determine the equivalence of the targets was a secondary objective. The order of presentation used (the AO and the left eye always first rather than a counter-balancing of the two targets and of the two eyes) was deliberately chosen to meet the needs of the primary objective. The objection to counter-balancing for correlational analysis is that practice effects (if present) would differentially affect the scale of measurement in counter-balanced orders of presentation. This scale distortion would, in turn, spuriously influence the correlation between the targets.

On the other hand, counter-balancing is a necessity when the determination of equiva-lence is the primary concern. Otherwise, practice effect (if present) would produce a difference in scores even though the targets were in fact equivalent in difficulty. In this study, changes in acuity scores which might have involved practice effect, at least from left to right eye, appeared to be negligible or nonexistent; as shown in Table 2, average acuity scores from left to right eye improved on AO but lessened on AFFVAT. Because of the slight magnitude and variation in direction of these changes, it is assumed that practice effect from test to test was also negligible in this study.

With these considerations in mind, Table 2, Table 3, and Figure 1 indicate that the AO is more difficult than the AFFVAT. For example, none of the men successfully read the 20/12 line on AO; in contrast, about 1/3 achieved 20/10 on AFFVAT. A lack of equiv-alence prevents interchangeable use of AO and AFFVAT under operating conditions, unless norms are adjusted empirically. For example, if 20/20 Snellen were set as a cutting score for a particular selection purpose, AO could not be used unless the cutting score was changed to approximately 20/30 Snellen.

Table 1 may be interpreted to show that AO and AFFVAT appear to be measuring much the same ability. Indeed, when the correlations were corrected statistically for the attenuating effects of unreliability of measurement, they approached unity.

COMPARISON OF AMERICAN OPTICAL AND BAUSCH & LOMB VISION TESTERS FROM THE POINT OF VIEW OF MECHANICAL CONSTRUCTION, OPTICS, ETC.

Louise L. Sloan and Adelaide Altman[1]
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1. Optical System

The viewing lenses of the AO instrument have an equivalent dioptric power of about 9D; those of the B&L instrument about 3D. The optic centers of the lenses of the AO instrument are separated by only 44 mm. in the distance tests, by 68 mm. in the near tests. If therefore the subject's eyes are located symmetrically with relation to the center of the instrument (i.e., his head is not shifted either to the left or to the right and a pd of 64 mm. is assumed), the visual axis of each eye will pass through its viewing lens 10 mm. outside the optic axis in the distance tests and 2 mm. inside the optic axis in the near tests.

In order to determine whether or not the resulting lens aberrations could produce a significant deterioration of acuity under conditions of actual testing the following experiments were made. The subject's head was held in a fixed position by means of a mouth-board. The instrument was mounted on a mechanical stage which permitted it to be moved laterally in relation to the subject's fronto-parallel plane. The acuity of the right eye was then measured for various lateral position of the eye relative to the center of the viewing window.

The two subjects examined showed no measurable change in distance acuity until the visual axis was 5 mm. outside the center of the viewing window, i.e., 15 mm. from the optic axis of the lens. At this location acuity suffered a sudden decrease, from 20/17 to 20/20 for one subject, from 20/15 to 20/17 for the other. When, however, the acuity of subject LS was artificially reduced to 20/40 by a convex lens, there was no measurable decrease in acuity even at 20 mm. from the optic axis of the lens. This finding suggests that the lens aberrations have the greatest effect when the subject's acuity is better than 20/40.

When the same two subjects viewed the near acuity targets, similar variations in location of the eye relative to the center of the viewing window did not result in any measurable effects on acuity, presumably because in the near tests the optic axis of the lens is only 2 mm. from the center of the viewing window and the visual axis therefore can never be as much as 15 mm. from the optic axis.

On the assumption that the subject's eyes are symmetrically located on either side of the center of the instrument, the distance between the optic axis of the lens and the visual axis will vary with the interpupillary distance. The critical location at which the lens abberrations become obvious (i.e., 15 mm. outside the optic axis) will be reached when the interpupillary distance is 74 mm. Data of Imus and Brogden[2] show that values of 74 mm. or greater occurred in 13 of 127 male negro subjects but in only 4 of 6533 white males.

The possibility of lateral shifts of the head in monocular tests must also be considered. With an interpupillary distance of 64 mm. an outward shift of 5 mm. is sufficient

2. OSRD Report No. 1341, March 24, 1943—Restricted.

to bring the visual axis into the critical region where lens aberration becomes noticeable. Measurements of the lateral variation in head position with the original flat brow rest showed that shifts of as much as 13 mm. were not unusual. With the curved brow rest, used I believe by everyone in this investigation, the lateral variation in location of the eye relative to the instrument was very much less. Measurements on three subjects showed variations of +0.7, +1.2 and +1.3 mm., respectively. It should be emphasized however that although we could detect no measurable decrease in acuity at distances within 15 mm. from the optic axis of the viewing lens, it is nevertheless possible that lens aberrations are significant within these limits. Whether or not this is so can only be determined from the experimental studies comparing the acuities measured on the AO instrument with those obtained under conditions in which lens aberrations may be considered of negligible importance. The fact that significantly lower acuities were found on the AO instrument, in the near as well as in the far tests, and with the curved brow rest, suggests either that aberrations play a significant role at distances closer to the optic axis than 15 mm., or that there are other factors acting to give lower acuities on the AO instrument. Possible factors are (a) lower background brightness, (b) poor reproduction of the test targets.

2. Background Brightness

At a voltage of 120, the background brightness varied in different areas from 9.4 to 11.3 ml. in our AO instrument, from 8.0 to 9.9 ml. in our B&L instrument. Although this is not a significant difference in the two instruments it should be noted that at 120 volts, the brightnesses are in both cases close to the lower limit of the specified 10-15 ml. range. At 105 volts the brightness was 5.8 to 6 ml. in the AO instrument 4.4 to 4.6 in the B&L. The decrease in voltage from 120 to 105 would decrease acuity by about 0.1 on a decimal scale; (for example from 20/20 to 20/22 or from 20/25 to 20/30). Unless the other instruments used in this study differed significantly from ours, it seems unlikely that differences in background brightness could be responsible for the lower acuity generally found on the AO than on the B&L instrument.

3. Reproduction of Test Targets

a. Acuity Targets. When the acuity slides are viewed in their respective instruments, the letters of the AO device appear thinner and less black. When however the test slides are removed from the instruments and are viewed side by side under high magnification these differences are no longer seen. The AO letters on Slide 3A appear just as black and the edges are as clean-cut as the B&L targets.

It seems possible therefore that the lack of clarity in the AO letters when viewed in the instrument may be the result of defects in imagery produced by the viewing lenses. Our data show only the abrupt increase in such defects when the visual axis is 15 mm. outside the optic axis. Less obvious aberrations could also be present when the visual axis is closer to the optic axis. We had no means of making accurate measurements of letter size. On the 20/20 line we did find variations from the correct size of as much as 5% but this was within the precision of our measuring device. More accurate measurements of letter size were made at New London and will be reported by that group.

b. Depth Slides. Production of the extremely small displacements required to give the simulated depth differences is technically more difficult than production of acuity and phoria slides of the required dimensions. Since the displacements on the AO slide must be only about one-third as great as those of the B&L slide to produce the same angular disparities, a correspondingly higher accuracy of reproduction is required. The formulae for converting linear displacements in mm. to angular disparities in seconds are

$$a = 622d \text{ for the B\&L instrument}$$
$$a = 1875d \text{ for the AO instrument.}$$

In the AO instrument therefore the displacements must be correct to within 1 micron (.001 mm.) if the errors in angular disparity are not to exceed +2 seconds. On the B&L slide the errors in linear units can be about three times as great.

Measurements on the depth slides of both instruments were made for us by Dr. Richard Tousey of the Naval Research Laboratory. On the B&L slide the deviations from the specified values range from 0.2 to 3.0 seconds. On the AO slide they range from 0.2 to 1.9 seconds. In spite of the smaller linear dimensions of the AO slides, the desired angular disparities have been reproduced somewhat more closely on the AO than on the B&L slides. Additional measurements made by Dr. Tousey suggest moreover that shrinkage of the film with changes in temperature and humidity do not produce significant alterations in the test characters.

Since reproduction of the depth slides requires a much higher precision than reproduction of the letter targets we came to the conclusion that the defects in the letter targets were probably the result of lens aberrations rather than of defects in the slides themselves. Although the data from New London did not bear this out, the level of accuracy achieved in the reproduction of the depth slides indicates that the letter slides could have been adequately reproduced on 35 mm. film.

CONCLUSIONS

Our findings suggest that if the lens system could be redesigned the AO instrument might give acuity measurements in closer agreement with those of the B&L machine. Unless however, there are important considerations which require an instrument as small as the present AO Vision Tester, it would be preferable to redesign the instrument on a larger scale. If the over-all dimensions were increased, lenses of lower power could be used, the mechanical parts could be more ruggedly constructed, and control of the target sizes would be less critical.

Table 1

EFFECT OF EYE POSITION ON VISUAL ACUITY

Lateral Distance of visual axis from center of viewing window	Lateral Distance of visual axis from optic axis of viewing lens	Interpupillary distance corresponding to this eye position	Lowest line on which errors were 30% or less Line No.	Acuity	Per Cent errors on this line
Subject L.S. —Distance acuity (without correction of slight refractive error)					
-13 mm.	- 3 mm.	38 mm.	10	20/17	10%
0	+10	64	10	"	20
+ 2	+12	68	10	"	15
+ 4	+14	72	10	"	20
+ 5	+15	74	9	20/20	10
+14	+24	92	8	20/25	30
Subject A.A. —Distance acuity (wearing refractive correction)					
-13	- 3	38	11	20/15	22.5%
0	+10	64	11	"	20
+ 3	+13	70	11	"	20
+ 5	+15	74	10	20/17	10
+ 7	+17	78	10	"	10
+10	+20	84	10	"	15
Subject L.S. —Distance acuity (slight artificial myopia)					
-14	- 4	36	6	20/40	5%
- 9	+ 1	46	6	"	--
+ 6	+16	76	6	"	30%
+10	+20	84	6	"	15%
Subject L.S. —Near Acuity					
-12	-14	40	10		5%
- 8	-10	48	10		"
0	- 2	64	10		"
+ 3	+ 1	70	10		15%
+12	+10	88	10		"
+13	+11	90	10		"
Subject A.A. —Near Acuity					
- 8	-10	48	11		27.5%
0	- 2	64	11		15
+ 8	+ 6	80	11		25
+10	+ 6	84	11		25

Table 2

ANGULAR DISPARITIES—DEPTH SLIDES

Group and Line	Specified	Measured B&L 5	B&L 5A	AO 5
B_1	40 sec.	39.8 sec.	40.7 sec.	39.0 sec.
B_2		41.0	39.2	38.6
B_3		39.8	39.8	40.5
C_1	30	32.3	32.3	29.1
C_2		30.2	30.5	31.9
C_3		31.1	31.1	31.1
D_1	25	26.4	25.5	25.2
D_2		25.2	25.2	23.2
D_3		28.0	28.0	25.4
E_1	20	20.8	21.5	19.3
E_2		20.5	20.8	19.5
E_3		21.2	20.8	20.6
F_1	15	16.2	16.8	17.8
F_2		15.9	15.2	16.1
F_3		16.5	16.5	14.6
Av. Deviation from Specified		1.05	1.06	1.02
Greatest Deviation		3.0	3.0	1.9

VISUAL STANDARDS FOR PILOTS IN NATO

Benjamin J. Wolpaw
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A Vision Subcommittee of the Aeromedical Panel of the NATO countries met during December 1953 and prepared a preliminary set of visual standards for pilots of these nations. A working group consisting of Dr. H. W. Rose, Capt. Philip T. Shahan, USAF(MC), Lt. Thomas G. Dickinson, MC, USNR, and Dr. B. J. Wolpaw, Chairman, met subsequently to review the visual standards suggested for NATO pilots and to compare these standards with those of the United States Air Force and Navy. This is a brief review of the essential thoughts presented in the preliminary study.

1. It is impossible to obtain sufficient pilots, in all nations, who could meet ideal standards. The pilots were, therefore, broken down according to visual requirements into four groups:

(a) Fighter and reconnaissance pilots (with the best vision)
(b) Bomber pilots
(c) Helicopter pilots (require especially good depth perception)
(d) Liaison and transport pilots.

The present study concerns only fighter pilots since they are of the greatest importance.

2. <u>Color Vision</u>. About 8 to 9% of candidates who would otherwise qualify are rejected in the European countries for this cause alone. This is too large a percentage of men to lose. It was recommended that consideration be given to the selection and standardization of colors for maps, lights, flares, signals, and other tasks which would allow their use by color defectives as well as by persons with normal color vision.

3. <u>Visual Standards</u>

(a) Acuity. Three standards were believed desirable:
1. Ideal (better than normal: combat pilots)
2. Normal (minimum for combat pilots)
3. Minimum (for other than combat pilots)
Normal vision is meant to be 20/20 in each eye without correction. In the United States, 20/20 uncorrected in each eye is required only of student pilots. Having earned his wings, a pilot must have 20/50 in each eye, correctible to 20/20 in the Air Force, and 20/30 correctible to 20/20 in the Navy.

(b) Refractive errors. The suggested NATO standards were very similar to those in force in this country.

(c) Heterophoria standards. These were similar to the United States requirements.

(d) Prism divergence, binocular fixation, convergence ability, accommodation, field of vision, and depth perception requirements were similar to those in force in the United States.

The working group finds the suggested NATO visual standards very similar to those in force in the U.S. Air Force and the U.S. Navy, with the exception of the visual acuity for fighter pilots. The requirement of 20/20 in each eye uncorrected is higher than the required vision in either of this nation's air forces.

REPORT OF THE
WORKING GROUP ON MIDSHIPMAN MYOPIA AT ANNAPOLIS

Dr. Glenn A. Fry, Chairman

PREFACE

The Superintendent of the United States Naval Academy, by letter of 1 February 1954, initiated a request that the Armed Forces-National Research Council Vision Committee render consultative advice concerning various aspects of the problem of midshipman myopia encountered at the Academy. The general problem was described in the following terms:

"As might be expected with the age group represented by midshipmen at the U.S. Naval Academy there is a serious visual problem in the development of myopia.

"The Armed Forces-National Research Council Vision Committee very kindly sent a working committee to the Academy on 1 October 1950. At this time the problem of visual requirements for entrance and for commissioning was discussed. Advice was given by the Committee which has been followed.

"The visual problem, however, is still pressing and many of the midshipmen feel that the reason for their loss in visual acuity can be traced to improper lighting or wrong color or texture of paint in their rooms. Various commercial representatives have made recommendations but we hesitate to make any further major alterations without expert advice from an impartial source.

"Therefore it is requested that the Armed Forces-NRC Vision Committee be asked to send a small working committee to examine the present conditions and make recommendations."

A working group was appointed by the Executive Council of the Vision Committee, consisting of the following members:

Dr. Conrad Berens: Managing Director, The Ophthalmological Foundation, New York

Dr. Louise Sloan: Laboratory of Physiological Optics, Wilmer Institute, Johns Hopkins Medical School

Dr. Glenn A. Fry (chairman): Director, School of Optometry, Ohio State University

Subsequently, a sub-working group to survey lighting conditions was appointed, consisting of the following members:

Captain John T. Smith (MC)USN: American Board of Preventive Medicine; and Medical Officer, Staff, Commander, Air Force Atlantic

Commander Dean Farnsworth (MSC)USNR: Head, Human Engineering Branch, Naval Medical Research Laboratory, U.S. Naval Submarine Base, New London, Connecticut

Mr. Ray P. Teele: Physicist, National Bureau of Standards

Members of the working group and of the sub-working group met at the Academy on March 31. The following personnel of the Academy presented their analysis of the problem:

Captain Charles W. Shilling, Senior Medical Officer; Commander Robie; and Dr. Parker Lee. Dr. Sloan reviewed the work of Commander Hynes, formerly of the Academy, and the work of the previous working group of the Vision Committee, referred to above. Dr. Berens reviewed the work which has been done on the problem of cadet myopia at West Point. The sub-working group made a careful survey of the lighting at the Academy. After considerable discussion, the working group prepared their conclusions and recommendations in the form of a report to the Vision Committee.

The report of the working group was presented to the Vision Committee for consideration at the session on April 1, 1954. The report of the working group was approved by the Vision Committee for transmittal to Captain Charles W. Shilling of the U.S. Naval Academy.

The report is divided into two sections: (a) a report of the survey of lighting at the Academy, and (b) a summary of general comments concerning midshipman myopia.

(a) REPORT OF THE SURVEY OF LIGHTING AT THE U.S. NAVAL ACADEMY

Photometric inspection of representative rooms revealed that the lighting fixtures provided, at desk height, an illumination which varied from 15 foot-candles on a desk by the wall to 60 foot-candles on a desk in the center of the room. By proper arrangement of the furniture, each Midshipman could have available 30 foot-candles at his desk. This level of illumination is considered to be adequate for the visual tasks required of Midshipmen.

It is concluded that complaints of poor lighting in Midshipmen's study rooms arise not because of inadequacy of the level of illumination, but because of the poor contrast characteristics of the Midshipmen's study environment. White writing paper and book page surfaces have approximately 80% reflectance. Reflectance values of other materials in the visual field were measured and found to be as follow: desk tops 4%; decking 10%; and lockers 6%. The resultant contrast ratios are, therefore, as high as 1:20. This far exceeds desirable ratios, which are in the order of 1:3.

To obtain more desirable contrast ratios economically, the following is recommended:

1. Change present green desk blotters to gray blotters of 35% to 55% reflectance.

2. Re-cover desks with light gray linoleum of reflectance 35% to 55%.

3. Re-finish lockers with a paint of 45% to 60% reflectance. Bureau of Ships "green gray" originally designated for submarine service and made standard in February 1951 will accomplish the desired effect.

4. Replace the dark brown floor with a lighter colored material when opportunity arises. Floor covering of 20% to 40% reflectance would accomplish the desired effect.

It is concluded that the lighting installation in the study rooms of Bancroft Hall, as it exists today, is not detrimental to the visual acuity of Midshipmen. However, the items criticized above produce an uncomfortable visual environment which can well be the source of justifiable complaint and which can actually reduce study efficiency. It was noted that some Midshipmen placed their desks in very poor relationship to the lighting fixtures.

It is known that some Midshipmen have requested permission to purchase desk lamps for their rooms in Bancroft Hall. Although desk lamps would provide a more comfortable study environment, it is concluded that acquiring desk lamps would have no effect in preserving the visual acuity of Midshipmen. However, if the funds become available,

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further improvement in visual comfort could be obtained by desk lamps, properly designed and installed under the supervision of a qualified illuminating engineer.

Since it is concluded that the level of illumination is adequate for the study tasks of Midshipmen in Bancroft Hall, the expense of changing the present lighting fixtures is not considered justifiable.

(b) A SUMMARY OF GENERAL COMMENTS CONCERNING MIDSHIPMAN MYOPIA

1. There is no evidence to show that anything about the Naval Academy, its curriculum, methods, diet, or environment, predisposes to refractive errors and loss of distance or near vision.

2. There is no evidence that the use of normal eyes for close work or study produces visual defects or aggravates them.

3. There is no evidence that the quality of illumination, as now exists at the Naval Academy, has any predisposing effect upon the reduction of visual acuity. Furthermore, its intensity is within the rather wide range of hygienic desirability, and therefore could have no deleterious effect.

4. It is certain that the development of most myopic errors of refraction is genetically determined, and it appears established that the age at which myopic defects appear is related to the growth process which is also genetically predetermined.

5. If the health, diet, and environment meet satisfactory standards of hygiene, there is no method for preventing developmental myopia.

6. In a study by Commander Hynes at the Naval Academy it was conclusively proven that it is possible by an examination under cycloplegia to predict and therefore eliminate almost all of those men who will develop myopia during their four years at the Naval Academy. We recommend that the practice of making a cycloplegic and post-cycloplegic refraction at the entrance examination be re-instituted. However, if this is done one must face the fact that the available pool of applicants will be drastically reduced.

7. The only other solution is to accept for Line duty men with lower distant visual acuity. This has been done to a limited extent by reducing commissioning requirements from 20/20 to 20/40 with a trial period and waiver for those as low as 20/100. We recommend that the 20/100 waiver be continued and that Line officers continue to be commissioned with 20/40 vision without waivers providing the glasses used correct the vision to at least 20/25 in each eye and provided the eyes are free from active diseases.

These slightly amplified recommendations are in complete agreement with the ideas which have been so well expressed by Captain Charles W. Shilling. In order to carry out these recommendations, it will be necessary to have additional personnel in the eye department. The ophthalmologist obtained should be assigned for at least a three-year tour and should have the assistance of a full-time optometrist.

In order to assess the benefits of this program and to determine what modifications might need to be made, it is recommended that a visual examination be made at entrance and each year thereafter which would include tests for:

(1) Manifest refraction, (2) Visual acuity, (3) Phoria and vergence tests at far and near, (4) Amplitudes of accommodation and convergence, (5) in addition, a cyclopegic examination and a thorough test for color blindness should be given upon entrance to the Naval Academy and at the completion of the program before commissioning.

DISCUSSION

Dr. Wolpaw moved that the report of this Working Group be accepted. The motion was seconded by Dr. Sulzman, and passed by the Committee.

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A PHENOMENON OF APPARENT VISUAL PHOTOSENSITIZATION*

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ABSTRACT

The hypothesis that certain conditions of visual excitation during the course of dark adaptation are associated with a phenomenon of apparent photosensitization is advanced and documented. It is concluded that the several independent reports of such a phenomenon are in accord with experimental observation and that the hypothesis is correct. Experimental evidence is adduced which indicates that red light is more effective than light of shorter-wavelength composition in mediating this effect and that the apparent photosensitization is of greater magnitude when the observer is not adapted to a high brightness at the start of the exposure period. It is shown, however, that the superior effectiveness of red light cannot be accepted as definitive of the wavelength-sensitivity function of the phenomenon. A theoretical analysis of the serial-exploration techniques of threshold-determination reveals the possibility that the phenomenon may be more directly associated with changes in response-variability than with changes in the brightness threshold.

I. REVIEW OF THE LITERATURE

A. Aubert (1865) and Helmholtz (1911)

Since the time of the first systematic investigation of dark adaptation in the human eye[1], the hypothesis that a latent reduction in the brightness threshold of the dark-adapted human eye is associated with exposure to stimuli well above liminal intensity has repeatedly been advanced. Among the earliest instances of such reports were the observations of Aubert[1] and of Helmholtz[2], which are well summarized in the following quotation from Helmholtz' Handbook[2]:

> "Aubert noticed that the progress of dark adaptation was not only not impeded by flashes of light considerably above the liminal intensity, but that, in fact, it was aided in some measure. This observation has since been confirmed many times in the writer's laboratory. That the instantaneous light of a match reflected from dark walls into the observer's eye lowers the threshold of the light sense considerably, as much perhaps as one-third, can easily be verified. This effect does not wear off for several minutes. It is particularly distinct when the observer has reached a practically stationary condition of adaptation after having been in the dark for an hour."

B. Kravkov and Semenovskaya (1935)

In 1935, Kravkov and Semenovskaya[3] reported a somewhat similar phenomenon—an apparent photosensitization—but with contra-lateral exposure. The plan of this experiment is illustrated in Figure 1. Following adaptation to two lux (white light) for fifty minutes, the control group remained in total darkness for seventy minutes except for right-eye threshold determinations and the experimental group underwent exactly the same procedure

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except for ten minutes' exposure of the left eye to 220 lux. The right eye was occluded during the left-eye exposure period.
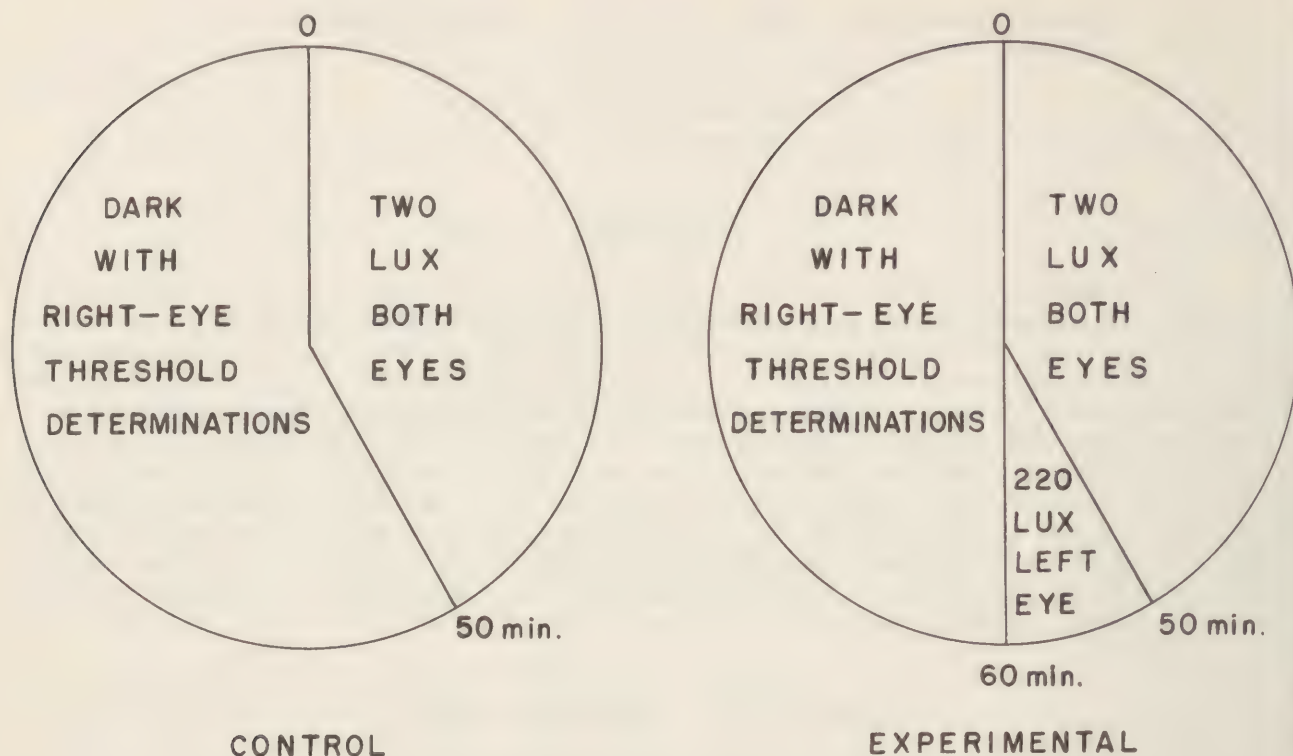

Figüre 1. Plan of experimentation: Kravkov and Semenovskaya (1935).

The effect of the left-eye exposure, as indicated by comparison between experimental and control threshold data, was to raise the right-eye threshold for ten minutes (minutes 60-70 in Figure 1) and then, for the remaining fifty minutes, to lower it below its normal "total-darkness" value. In another experiment of the same series, Kravkov and Semenovskaya reported even greater "photosensitization" when red rather than white light was used during the left-eye-exposure period.[3]

C. Admiralty Research Laboratory (1942)

A more detailed account is available of experiments carried out at the British Admiralty Research Laboratory in November, 1942[4,5]. Preliminary white-light adaptation in these experiments was to seven ft-c for one hour. Threshold determinations were binocular and involved some form perception, a forced-choice mode of response[6], and a psychophysical method of serial exploration with a single descending-brightness series[7].

As shown in Figure 2, the 24 observers of the control group remained in total darkness for thirty-five minutes following pre-adaptation. Each experimental group was exposed to red light immediately following pre-adaptation, then remained in total darkness except for threshold determinations. As an additional control datum, the mean thirty-minute dark-adapted threshold for each experimental group, without exposure to red light, was made available for comparison with that of the control group. For the data to be considered here, the mean thirty-minute dark-adapted threshold of each experimental group was exactly equal to that of the control group.

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O

DARKNESS
WITH
THRESHOLD
DETERM.

35'

Control Group

O

RED
LIGHT   10 or 20

DARK
WITH
THRESHOLD
DETERM.

35'

Experimental Group
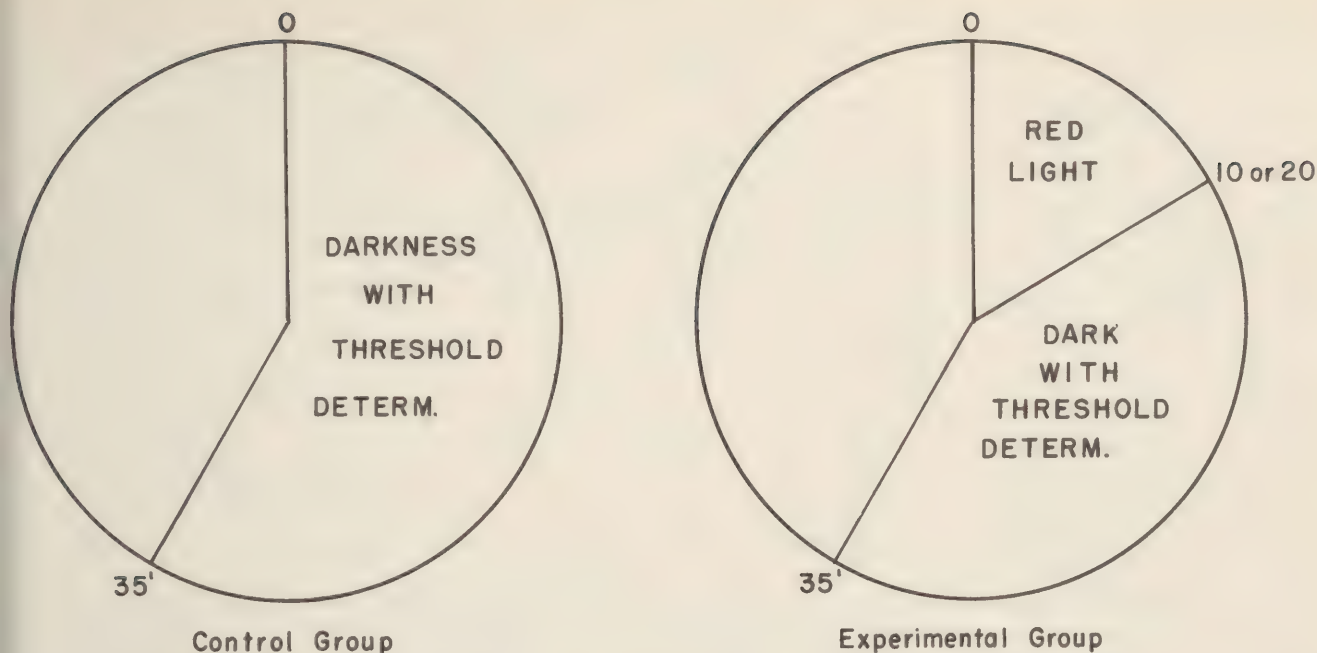
Figure 2. Plan of experimentation: ARL/N6/0.360 (1942).

Figure 3 shows the full dark-adaptation curve for the control group and threshold data for two experimental groups. Red-light exposure was to 0.3 ft-c red: ten minutes for one experimental group and twenty minutes for the other. A latent reduction in threshold by 0.3 log unit, apparently associated with red-light exposure, may be noted in these data. As shown in Figures 4 and 5, other experiments of this series indicated that even greater "photosensitization" could be obtained by the use of lower intensities of red light[4], and that significant but smaller reductions in threshold were associated with exposure to lights of orange and amber hue[5].

The following quotation, from the publication which included the data of Figures 3 and 4, is also of some interest to the present discussion:

"Reports have been received from sea to the effect that very rapid dark adaptation can be obtained by 'looking at the port light' for a short period on going on deck from a lighted room."[4]
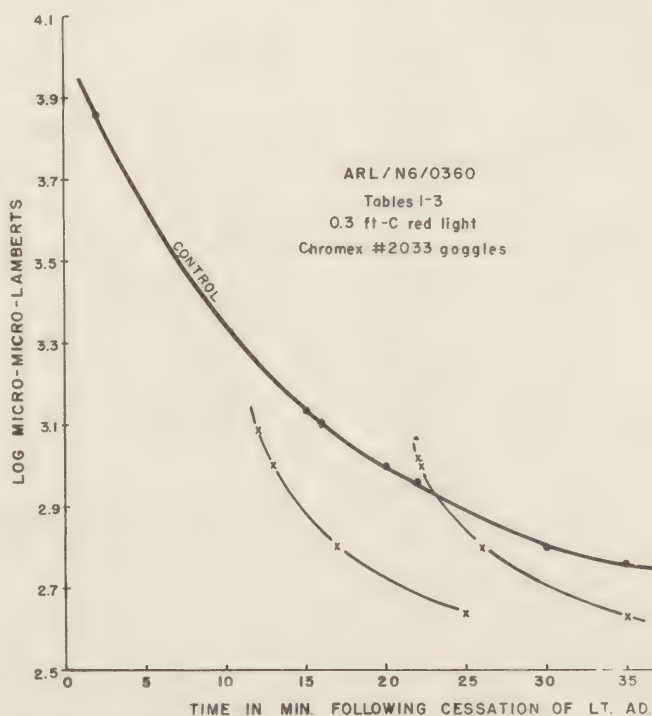
Figure 3. Comparison of control threshold data with thresholds following exposure to 0.3 ft-c red light. Duration of exposure was ten minutes for one experimental group and twenty minutes for the other. ARL/N6/0.360 (1942).

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D. Miles (1943, 1953)

In the Federation Proceedings for June, 1943, there appeared a paper entitled: "Red Goggles for Producing Dark Adaptation,"[8] by Prof. Walter R. Miles of Yale University. It will be convenient to consider at this time both the 1943 report and the additional data which Dr. Miles published in the Journal of the Optical Society in June, 1953.[9] For this purpose, sequential designations which did not appear in the original publications will be applied to Prof. Miles' several experiments in the following resume.

All of these experiments employed a Hecht-Shlaer adaptometer,[10] and the method of testing invariably consisted of a single ascending-brightness series of discrete test stimuli.[7] In Experiments I and II, light adaptation was to the adapting field of the adaptometer, which had a brightness of 1500 mL. In Experiment III, light adaptation was to 693 mL. The red light used in all three experiments had a brightness of about 0.3 mL.

The plan of Experiments I and II is illustrated in Figure 6. The center diagram of this figure shows the method of obtaining control data: light adaptation was followed by total darkness with enough threshold determinations to show the general course of dark adaptation. In Experiment I, these control data were compared with thresholds following 25-30 minutes' exposure to red light. Experiment II was designed to equate the experimental and control adaptation sessions with respect to quantity of test-light exposure: threshold determinations (with the red light off) were interspersed with periods of red-light exposure.
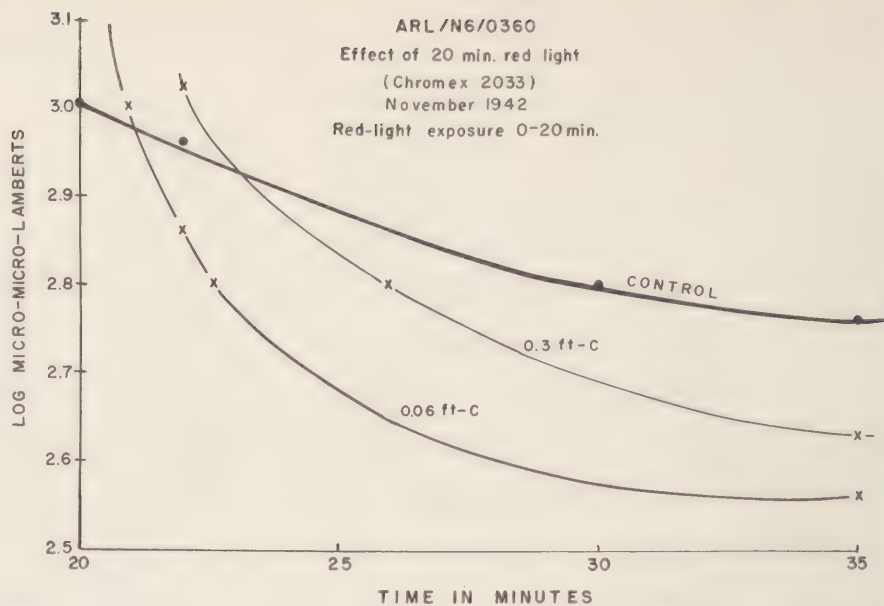
Figure 4. Comparison of two brightnesses of red light with regard to their effect on subsequent dark adaptation. ARL/N6/0.360 (1942).
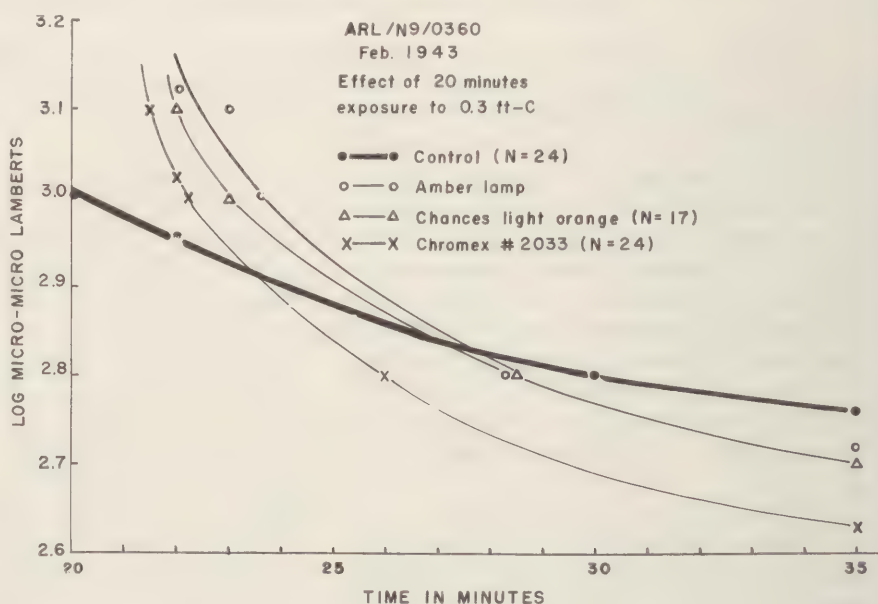
Figure 5. Comparison of red, orange, and amber exposure lights with regard to their effect on subsequent dark adaptation. ARL/N9/0.360 (1942).
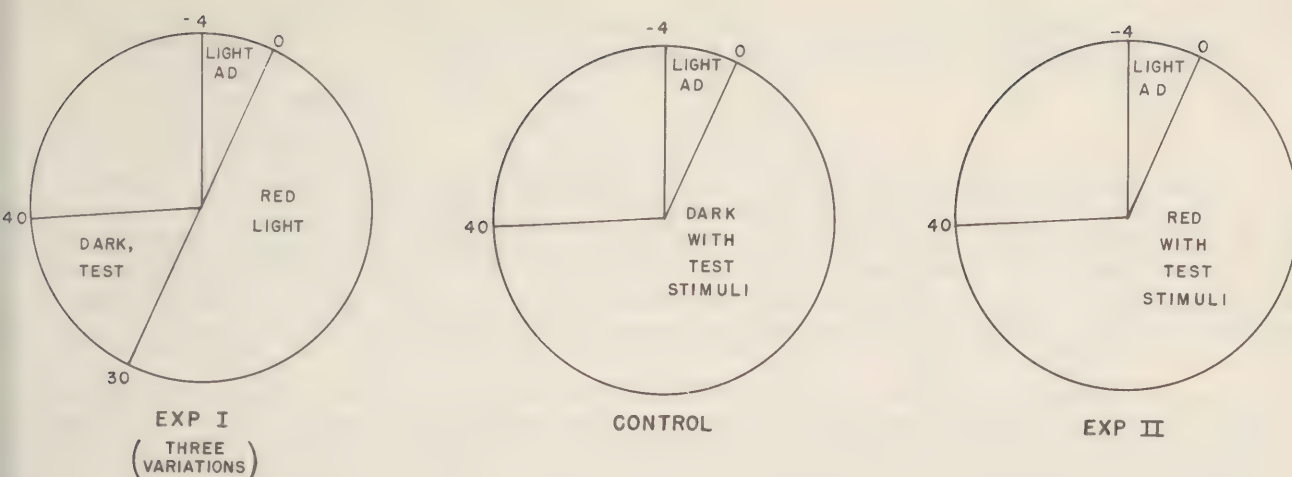
Figure 6.   Plan of Experiments I and II (Miles, 1943 and 1953).

Three distinct experiments were carried out on the general plan of Experiment I. Experiments Ia and Ib differed only in the size of the test stimulus, and gave mean reductions in threshold of 0.145 and 0.147 log unit, respectively.   In Experiment Ic, preliminary white-light adaptation was omitted in both control and experimental sessions, and the resulting mean reduction in threshold associated with red-light exposure was 0.264 log unit. The apparent photosensitizing effect of red-light exposure thus appears to have been vitiated by the relatively high level of pre-adaptation used in Experiments Ia and Ib.   This is borne out by the reduction in threshold of about 0.3 log unit obtained in the British experiments (Figure 3), where pre-adaptation was to seven ft-c.   It is also of interest to note that light-adaptation in the Kravkov-Semenovskaya experiment was to only two lux (about 0.2 ft-c), and that Aubert's pioneer studies of dark adaptation have been cited as noteworthy for their close agreement with later experimental findings in spite of Aubert's failure to pre-adapt his observers to a high brightness level.[11]

The results of Experiment II, for one observer, are shown in Figure 7. The vertical lines mark off the alternate red-light-exposure and test periods of the red-light adaptation session, those intervals marked "R" being the red-light-exposure periods.   Figure 7 is representative of the results obtained with each of the three observers employed in this experiment: about the same reduction in threshold occurred as in Experiment I.

In Experiment III, red-light exposure was monocular and of thirty minutes' duration, one eye being occluded during the red-light-exposure period. The results showed that the eye which had been exposed to red light had a slightly higher threshold (statistically significant only for the first six minutes following red-light exposure) than did the eye which had been kept in the
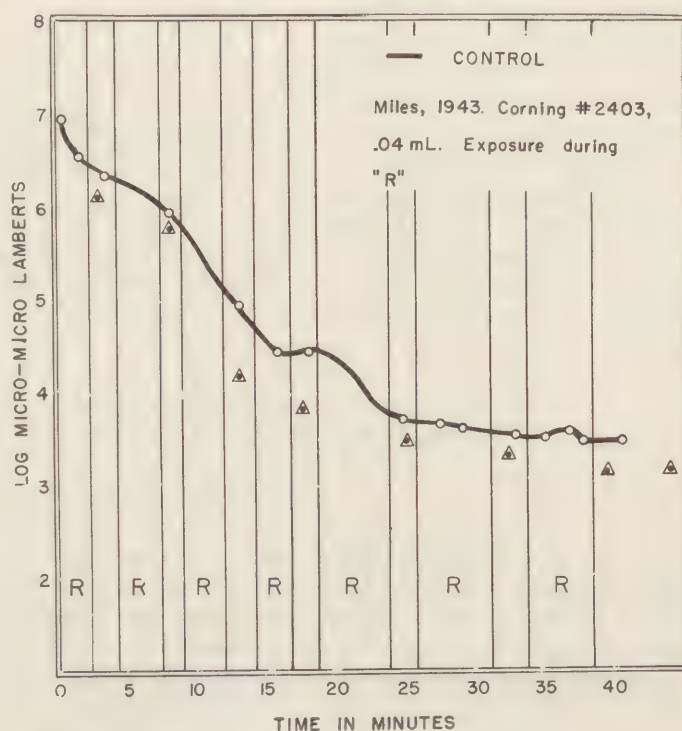

Figure 7.   Results obtained in Experiment II (Miles, 1943).

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dark. This is an interesting result, particularly in comparison with the Kravkov-Semenovskaya experiment described above. It does not, however, appear to provide any basis for questioning the validity of the findings of Experiments I and II.

E. Lee (1943)

In December, 1943, a report[12] entitled: "Comparison of Rates of Dark Adaptation Under Red Illumination and in Total Darkness," by Commander R. H. Lee, was issued by the Naval Medical Research Laboratory at Bethesda. Reference was made to the British experiments which have been described, and to Miles' 1943 paper. Lee's thresholds were determined by a method of adjustment[13] in which an ascending and a descending series were averaged to obtain each brightness-threshold value.

A representative portion of Lee's results is shown in Figure 8: thresholds obtained following red-light exposure were significantly higher than those obtained following a similar period in total darkness, the difference in favor of total darkness ranging from 0.1 to 0.5 log unit. The author concluded that this experiment "showed conclusively that exposure to a red light of these intensities (0.27 and 0.83 mL) raised the threshold appreciably above that to be found in complete darkness."

Lee's report did not contain any account of changes in variability of response associated with red-light exposure. Since, however, more recent experiments have indicated that response-variability may be important to the interpretation of Lee's findings, the following statement, in which Commander Lee refers to his 1943 experiment, is quoted with permission from a recent communication to the present writer:
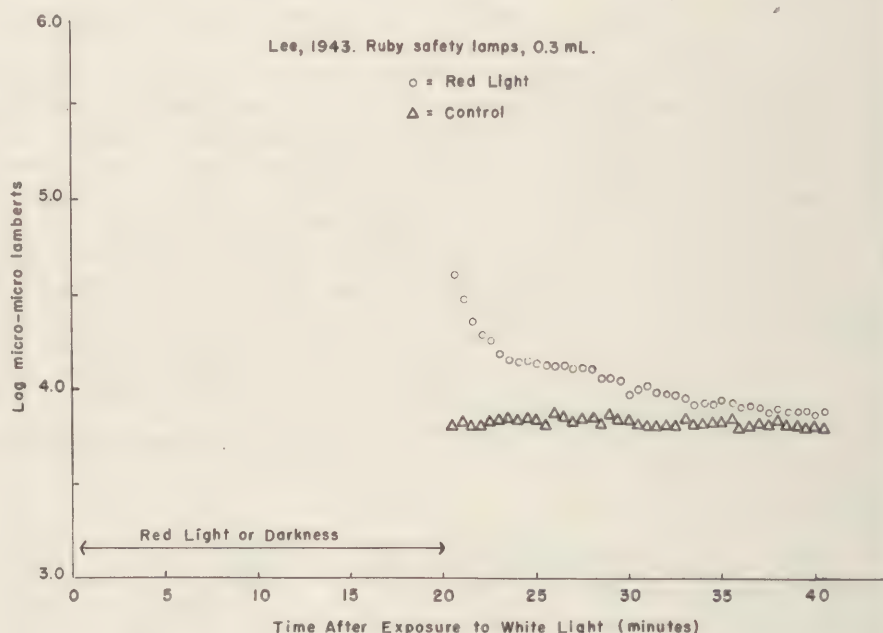
Figure 8. Results reported by Lee (1943) showing rise in threshold following red-light exposure.

"I found that the mean threshold was on the average higher with red light than with darkness, but that the spread of readings was greater."

F. Schoen and Dimmick (1948)

In April, 1948, there was published from the Naval Medical Research Laboratory at New London a report[14] entitled: "Relative Efficiency of Goggles for Dark Adaptation," by Drs. Z. J. Schoen and F. L. Dimmick. Four different pre-exposure conditions--including red light--were evaluated experimentally with regard to their effect on the cause of subsequent dark adaptation. Since no control data—i.e., no thresholds following "total darkness" as a pre-exposure condition—were included in that paper, the experiments there reported are evidently not relevant to the present discussion. However, the authors cited Miles' report of apparent red-light-photosensitization and stated as one of their conclusions:

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"If a subject is not expected to do anything else during the period of dark adaptation, he will adapt more quickly to the same level of sensitivity in complete darkness; but...if a group of subjects is being adapted, it is often easier to deal with them in a lighted room."

And in the Abstract section of their report, the authors state:

"Only if he gains by being occupied are goggles a time saver. If he must reach a certain level of dark adaptation in the shortest possible time, total darkness is more effective."

No reference is made by these authors to the Lee experiment, which might have provided some support for the statements here quoted.

G. Mitchell, Morris, and Dimmick (1950)

In December, 1950, a report[15] was published from the New London laboratory which cited the Schoen and Dimmick paper as having contradicted Miles' red-light-photosensitization finding. This was "The Relation of Dark Adaptation to Duration of Prior Red Adaptation," by Mitchell, Morris, and Dimmick. Lee's experiment was also cited, and the experimental results obtained were represented as providing additional evidence in favor of rejection of the data which had been reported by Prof. Miles. In this report, thresholds appear to have been significantly raised, rather than lowered, by red-light exposure.

Since Mitchell, Morris, and Dimmick used a red light approximately forty times as bright as the brightest red light which had previously been shown to be associated with red-light photosensitization, the results of their experiment cannot be regarded as constituting an adequate refutation of the results reported by Prof. Miles.

H. McLaughlin (1952)

In May, 1952, the present writer published from the Naval School of Aviation Medicine at Pensacola an account[16] of the experiment shown in Figure 9: each observer

a. Procedure for "Red Light" Session. b. Procedure for "Total Darkness" Session.
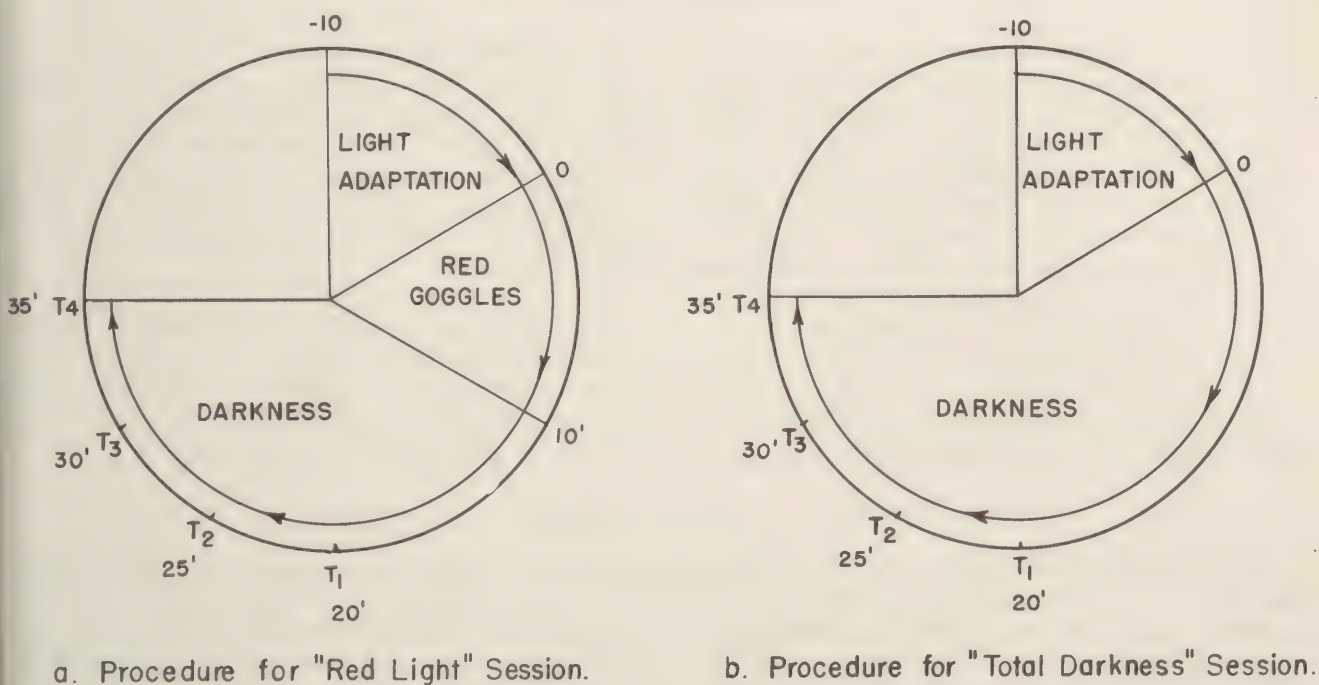
Figure 9. Plan of experimentation: McLaughlin (1952).

had two consecutive adaptation sessions with red-light exposure taking place in only one of them, as indicated in Figure 9. Some observers had the red-light session first and some had the total-darkness session first; the results showed that no reliable trend in favor of either exposure condition was associated with this parameter of the experimental design. Threshold determinations were made at 20, 25, 30, and 35 minutes after the cessation of light adaptation, using a method of serial exploration with an initial descending series[7] and ·phenomenal report.[6]

Figure 10. Mean thresholds following red-light exposure and total darkness (McLaughlin, 1952).
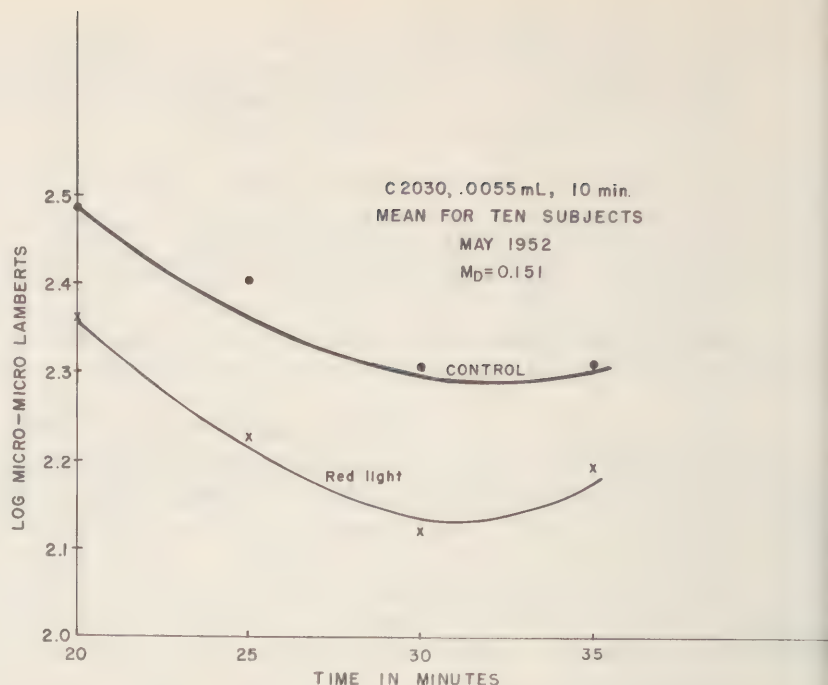
Figure 10 shows the mean thresholds obtained in this manner for ten observers. It may be observed that thresholds were lower following red-light exposure than following total darkness, the mean difference in favor of the red-light-exposure condition being 0.151 log unit. Since this logarithmic interval corresponds to a linear ratio of approximately 1.4, it may be said to represent a 40% increase in sensitivity.

I. Smith and Dimmick (1953)

With respect to conditions of light adaptation and red-light exposure, the writer's 1952 experiment was closely replicated by Mr. Stanley W. Smith and Dr. Forrest L. Dimmick at the New London laboratory in November, 1952.[17] However, Smith and Dimmick obtained thresholds by means of a method of constant stimuli[18] with phenomenal report, using six stimulus-brightnesses at intervals of 0.1 log unit. Test stimuli were presented without interruption during the fifteen-minute test period (minutes 20-35 in Figure 10). Phi-log-gamma functions[18] were fitted by visual inspection on log-Gaussian coordinates, the .50-intercepts of those functions being taken as thresholds.

Table I shows the results reported by Smith and Dimmick for five observers. Each datum in Table I represents the mean of two thresholds for one observer. Thresholds following red-light exposure were found to be substantially identical with those following total darkness, and no change in variability of response was found to be associated with red-light exposure.
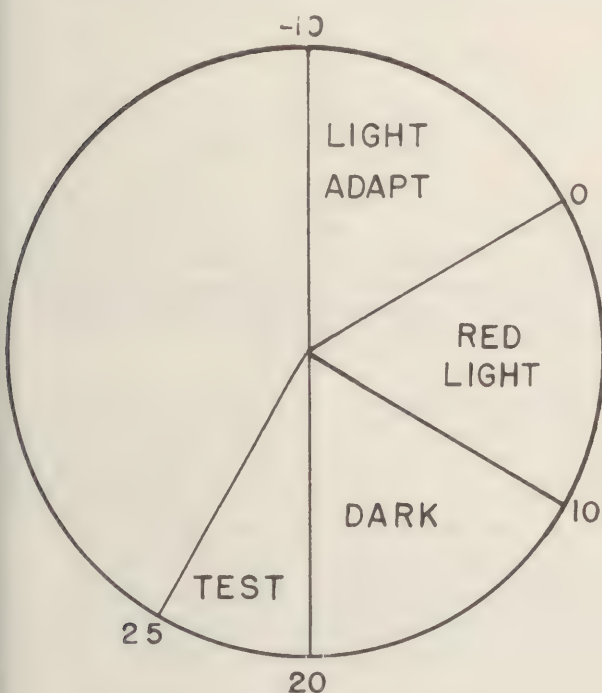
J. McLaughlin (1953)

The experiment shown in Figure 11, which was reported by the present writer from the Naval School of Aviation Medicine in August, 1953,[19] employed a constant-stimulus method with a positional-forced-choice mode of response.[6] Forty responses to each of two stimulus-brightnesses contributed to each threshold determination. The brightness interval between the two stimulus-brightnesses was invariably 0.2 log unit.

Table I

CONSTANT-STIMULUS 50% THRESHOLDS AND STANDARD DEVIATIONS OF PHI-LOG-GAMMA FUNCTIONS FOR EACH OF FIVE OBSERVERS FOLLOWING RED-LIGHT EXPOSURE AND TOTAL DARKNESS. The middle column shows the differences between red-light and darkness thresholds. Each datum represents the mean of two threshold determinations. (Smith and Dimmick, 1953.)

Subject	50% Threshold		Difference	Standard Deviation	
	Red	Dark		Red	Dark
PO	3.57	3.52	-0.05	.22	.18
FD	4.11	4.11	0.00	.20	.16
AM	3.92	3.92	0.00	.16	.18
JD	3.96	3.95	-0.01	.20	.18
JS	3.93	3.93	0.00	.24	.28
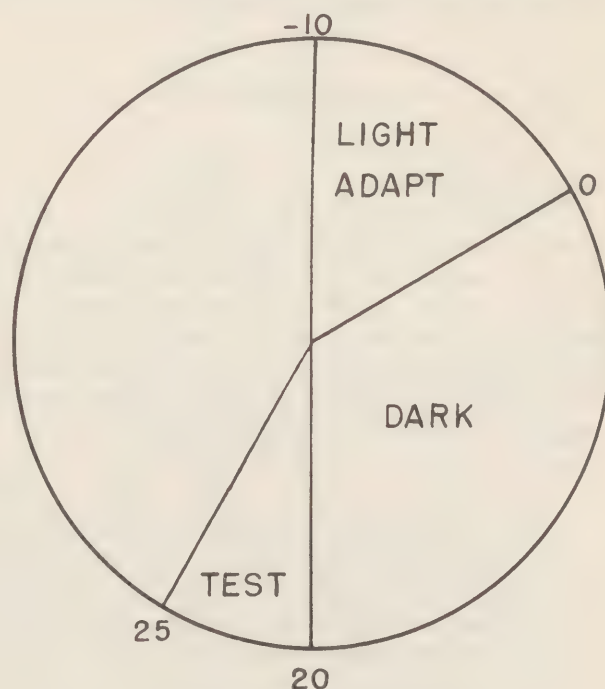
Figure 11. Plan of experimentation: McLaughlin (1953).

The method of analyzing the data is illustrated in Figure 12: after appropriate allowance had been made for the probability that a random response would be correct,[20] the proportion of correct responses to each stimulus brightness was plotted on log-Gaussian coordinates. The .50-intercept of the straight line so determined was taken as the "threshold," and the abscissal distance from the .50-intercept to the .16-intercept as the standard deviation of the phi-log-gamma function.[18] Only those threshold-determinations are reported for which the two stimulus-brightnesses subtended the liminal brightness.

Thresholds obtained in this fashion for four well-practiced observers are shown in Table II. The order of red-light and darkness sessions for each observer is indicated by the order of tabulation. Thresholds in log micro-microlamberts are shown in column 2. The data in column 3 are critical ratios for the differences between the two thresholds for each observer; in column 4 are shown the corresponding probabilities that the observed differences between red-light and darkness sessions for each observer are due to chance variation. These data appear to be in agreement with the results reported by Smith and Dimmick.

Column 5 of Table II shows the standard deviations of phi-log-gamma functions. It will be noted that the effect of red light in these experiments has apparently been to lower the standard deviation of the seeing-frequency function.

II. DISCUSSION

A. Statement of Hypothesis

The hypothesis here advanced is that certain conditions of visual excitation during the course of dark adaptation mediate a latent effect which is associated with changes in the brightness threshold and/or in the variability of response, and that this effect is manifested, under appropriate experimental conditions, as a phenomenon of apparent visual photosensitization.
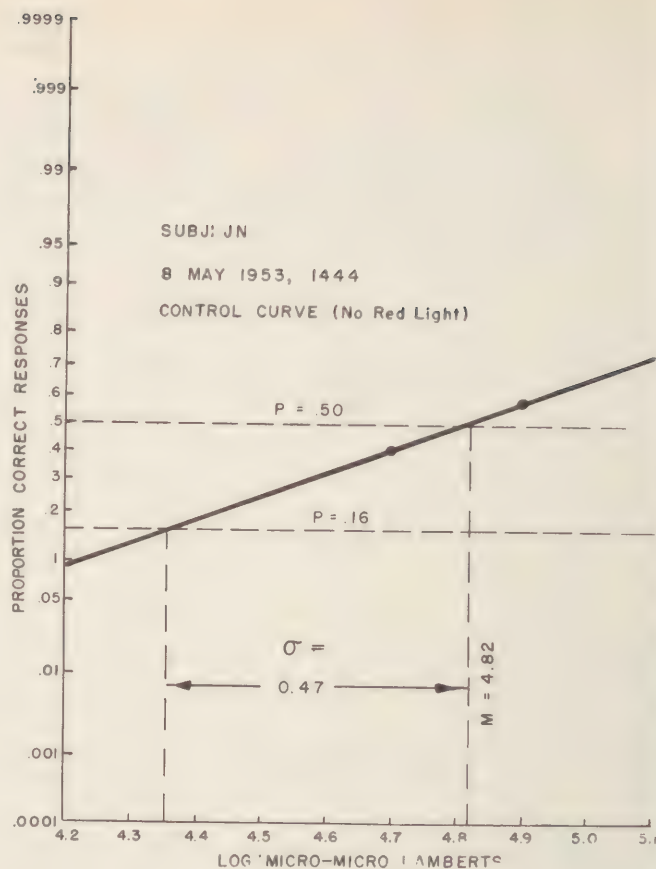
Figure 12. Method of obtaining thresholds and standard deviations of phi-log-gamma functions (McLaughlin, 1953). Coordinates are log-Gaussian, the experimentally-determined points are represented by solid dots, and the phi-log-gamma function is the straight line determined by those two points.

Table II

MEAN THRESHOLD AND STANDARD DEVIATION OF PHI-LOG-GAMMA FUNCTION FOR EACH OF FOUR OBSERVERS FOLLOWING RED-LIGHT EXPOSURE AND TOTAL DARKNESS. The experiment was replicated on subject CM. Values of the Critical Ratio and P_{nd} (see text) for the differences between red-light and darkness thresholds are shown for each observer. Data of McLaughlin (1953).

Subject	Red Light or Darkness	50% Threshold (Log $\mu\mu$L)	Critical Ratio	P_{nd}	Standard Deviation (Log $\mu\mu$L)
JN	Red Light	4.85	.54	.35	.18
	Darkness	4.82			.47
CM	Darkness	4.74	1.23	.19	.33
	Red Light	4.79			.15
LS	Darkness	4.80	.30	.38	1.19
	Red Light	4.84			.23
CM	Red Light	4.77	1.28	.18	.11
	Darkness	4.80			.18
DP	Darkness	4.94	1.11	.22	.79
	Red Light	4.80			.80

1. Interpretation of the Serial-Exploration Threshold-Determining Techniques
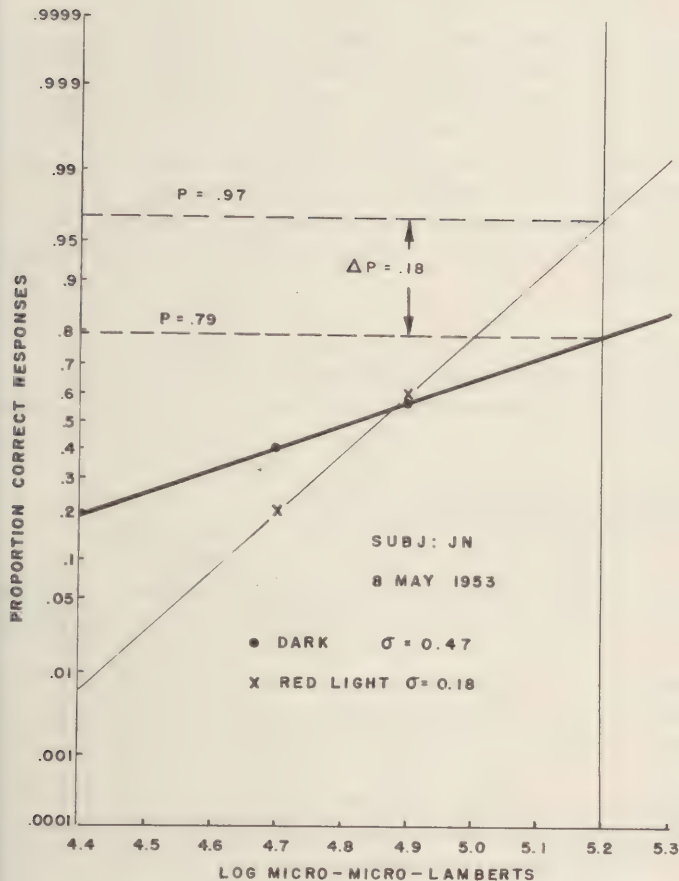

Figure 13. The effect of a change in standard devia-
tion on the probability that a supraliminal test-stimu-
lus (for example, one having a brightness of 5.2 log
micro-micro-lamberts) will elicit a positive or cor-
rect response.

Figure 13 shows, on log-Gaussian coordinates,
the two phi-log-gamma functions obtained for observer
JN in the writer's 1953 experiment:[19] one function
for a test period following twenty minutes of darkness
and one for a test period following ten minutes of red
light plus ten minutes in the dark. If the ordinal val-
ues in this figure be regarded as probabilities associ-
ated with the elicitation of a positive response, then it
may be noted that a decrease in standard deviation is
associated with an increase in that probability for any
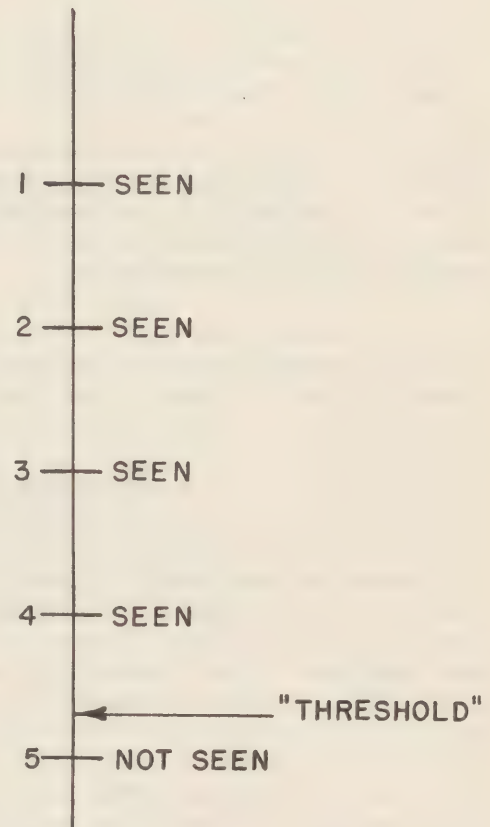supraliminal stimulus. For example, the observed de-

Figure 14. Schematic representation
of a single threshold determination by
a method of serial exploration with
discrete test stimuli, using a single
descending-brightness series of stim-
uli. The vertical line represents a
log-brightness scale, and the hori-
zontal lines represent test stimuli.
The temporal sequence of stimuli is
indicated by the number at the left of
each horizontal line, and the observ-
er's responses are shown at the right.
The "threshold" indicated is assumed
to have been determined by a con-
stant-stimulus method and to repre-
sent the test-stimulus brightness as-
sociated with a .50 probability of the
elicitation of a positive or correct
response.

decrease in standard deviation as a result of red-light exposure (0.47 to 0.18) has in-
creased from .79 to .97 the probability that observer JN will make a positive response to
a 5.2 log-micro-micro-lambert test stimulus.

Figure 14 is a schematic representation of a single threshold determination by a
method of serial exploration, using a descending-brightness series of discrete test stimuli.

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The vertical line represents a logarithmic scale of test-stimulus brightness. The "threshold" indicated is assumed to have been determined by a constant-stimulus method and to represent the brightness associated with a .50 probability of the elicitation of a positive response. Each horizontal line represents a test-stimulus presentation, the temporal sequence of such presentations being indicated by the numbers on the left.

When the standard deviation of the phi-log-gamma function approaches zero, positive or correct responses will be elicited by all stimuli above the indicated threshold, as shown in Figure 14. An increase in the value of the standard deviation will be associated with an increase in the probability that the descending series will be "prematurely" terminated by a negative response to a supraliminal stimulus, and thus that the observed brightness threshold will be higher than the brightness of test stimulus number four of Figure 14. Conversely, a decrease in standard deviation in comparison with its "normal" value, will, on the average, bring about a lowering of the observed threshold when a descending-series method of limits is employed.

In general, therefore, it may be said that changes in response-variability will be manifested as changes in brightness threshold when serial-exploration threshold-determining procedures are employed. The examination of the evidence from this point of view will now be undertaken.

2. Analysis of Experimental Evidence in Terms of Response-Variability

Since the writer's 1952 experiment[16] employed a method of serial exploration with an initial descending-brightness series, and since the writer's 1953 finding[19] was that a reduction in response-variability was associated with red-light exposure, it may be concluded that those two sets of results are not contradictory. It would appear that the effect of red-light exposure in both experiments was to reduce the variability of response, and that no alteration of the brightness threshold need be assumed for the 1952 data.

To the extent that the Admiralty Research Laboratory experimental results[4,5] are manifestations of changes in response-variability rather than in the magnitude of the brightness threshold, they agree with the writer's finding that red-light exposure mediates a reduction in variability of response, since the British investigators obtained apparent photosensitization using only descending-brightness series of stimuli.

Miles,[8,9] on the other hand, obtained apparent photosensitization using only ascending series. It would therefore appear necessary to conclude that, for the conditions of Miles' experiments, red-light exposure mediated either a reduction in brightness threshold or an increase in variability of response.

Since each of Lee's threshold values[12] represents the mean of the terminal brightnesses of an ascending and a descending series, the availability of seeing-frequency data for the conditions of Lee's experiment would appear to be necessary for the interpretation of Lee's results in terms of response-variability; the qualitative scheme outlined above does not suffice. We have, however, Lee's statement that "the spread of readings was greater" following red-light exposure, and it appears necessary that such an increase in variability would be associated with an increase in the standard deviation of the seeing-frequency function. Whether or not there was also a raising of the brightness threshold remains, for the present, indeterminate.

The present status of our understanding of the critical experimental parameters of the phenomenon under consideration does not appear to be adequate to explain these several conflicting findings with respect to the effect of red light on the variability of response. It may be regarded as likely, however, that red-light exposure interacts with certain

parameters of the testing situation in mediating such changes, and that further research designed to clarify this interaction might lead to the discovery of techniques for producing either type of latent effect at will.

With regard to the findings of Aubert,[1] of Helmholtz,[2] and of Kravkov and Semenovskaya,[3] sufficient information regarding the techniques of threshold-determination and other details of those experiments is not available to permit their analysis in terms of response-variability. Those experiments differed in several respects from the more recent investigations, and the possibility of an actual reduction in brightness threshold for those conditions of experimentation cannot be discounted.

Mention has been made of the necessity for regarding the findings of Schoen and Dimmick[14] and of Mitchell, Morris, and Dimmick[15] as not relevant to the hypothesis under consideration. It would appear, then, that only the Smith-Dimmick findings[17] fail to confirm the hypothesis: Smith and Dimmick reported that red-light exposure had substantially no effect either on brightness threshold or on variability of response.

In view of the relatively large body of experimental evidence which contradicts the Smith-Dimmick finding, it would appear reasonable to regard that experiment as a special case within the general framework of the hypothesis which is supported by all other available experimental data; namely, as that particular combination of experimental conditions in which those factors acting to raise the variability of response were equal in effectiveness to those factors which tended to lower it. The conflicting response-variability results reported by Lee and by Miles, on the one hand, and by the present writer and the British investigators, on the other, support this interpretation of the Smith-Dimmick experimental conditions as being intermediate between those two extremes.

It is appropriate in this connection to direct attention to the relatively large amount of test-light exposure which characterized the Smith-Dimmick method. It is not convenient to present at this time a detailed criticism of the Smith-Dimmick experiment from this point of view. Such a criticism might be based on the finding of Piper (1903)[21] that, under certain experimental conditions, barely supraliminal stimuli mediate a greater decrease in dark-adapted sensitivity than do stimuli which are well above the liminal intensity. The present writer's 1953 experiment[19] was, in fact, expressly designed to remedy this difficulty and to obtain constant-stimulus thresholds with a minimum of test-light exposure. In particular, the use of only two stimulus brightnesses separated by 0.2 log unit and the employment of a positional-forced-choice mode of response (thus ensuring that no one retinal area received every test stimulus) were dictated by this consideration.

These arguments, and, indeed, all of the experimental evidence here reviewed, appear to indicate that the effect of red-light exposure on variability of response is of cardinal importance to an understanding of the phenomenon here under consideration, and that the further experimental investigation of apparent visual photosensitization might well take as its first objective the study of the interaction of red-light exposure with other experimental conditions in mediating changes in response-variability.

It may also be observed that the hypothesis here advanced (Section II. A) is confirmed by the available experimental evidence.

3. Apparent Visual Photosensitization as a Phenomenon of Response-Variability

As indicated above, it is entirely possible that the apparent photosensitization reported by several investigators is related solely to changes in the variability of response, and that the constant-stimulus "50% brightness threshold" has remained unaltered under the conditions of all those experiments. It will therefore be relevant to examine the question of the importance and usefulness of such a phenomenon.

From the theoretical point of view, the researches of Dr. William Crozier[22] have demonstrated, and continue to demonstrate, the fruitfulness for visual theory of the analysis of response-variability. Dr. Crozier has shown that changes in variability of response are not only equal in theoretical significance to alterations in magnitude of threshold, but that the study of such changes is in fact basic to an adequate theoretical interpretation of the concept of a sensory threshold.

The present writer's finding[19] of variations in the standard deviation of the seeing-frequency function in the absence of changes in the brightness threshold confirm Crozier's hypothesis that the mean and variance of that function vary independently. This hypothesis has been advanced by Dr. Crozier as an argument against the fitting of Poisson integrals to seeing-frequency data.

From the practical point of view, it may be noted that the 50% "frequency of seeing," which is commonly taken as the "threshold," is of little significance in operational situations: it represents the target-brightness at which a night pilot, for example, has only a 50-50 chance of spotting an enemy plane. The brightness associated with a probability of .90 or higher is the "threshold" which is of military importance. Figure 15 shows the effect of a change in standard deviation on the "95% threshold" for observer JN of Table 2.[19] It may be noted that the change in standard deviation associated with red-light exposure has lowered from 5.59 to 5.16 the brightness associated with that threshold: a difference of 0.43 log unit. Since that logarithmic interval corresponds to a ratio of 2.7, it may be concluded that, for some practical purposes, red-light exposure under the conditions of that experiment effected a nearly threefold improvement in night-vision performance for subject JN with no change in the "50% threshold."

C. Spectral Quality of Red Light

Most of the experiments here reviewed have dealt with the effects of red rather than white light, and some[3,5] have provided indications that red light

Figure 15. The effect of a change in variability of response on the "95% threshold."

is more effective in mediating the subject phenomenon than is light of other spectral composition. There is no basis for assuming, however, that this superiority of red light over light of other wavelengths cannot be explained on the basis of the relatively small amount of red stimulation which characterizes red-light exposure as compared with exposure to white light of equal photopic luminosity.[8,23] It therefore appears reasonable to regard the "red-light photosensitization" reported by later investigators as a special case of a more general phenomenon, and to consider that no information is at present available regarding the wavelength-sensitivity function of that phenomenon.
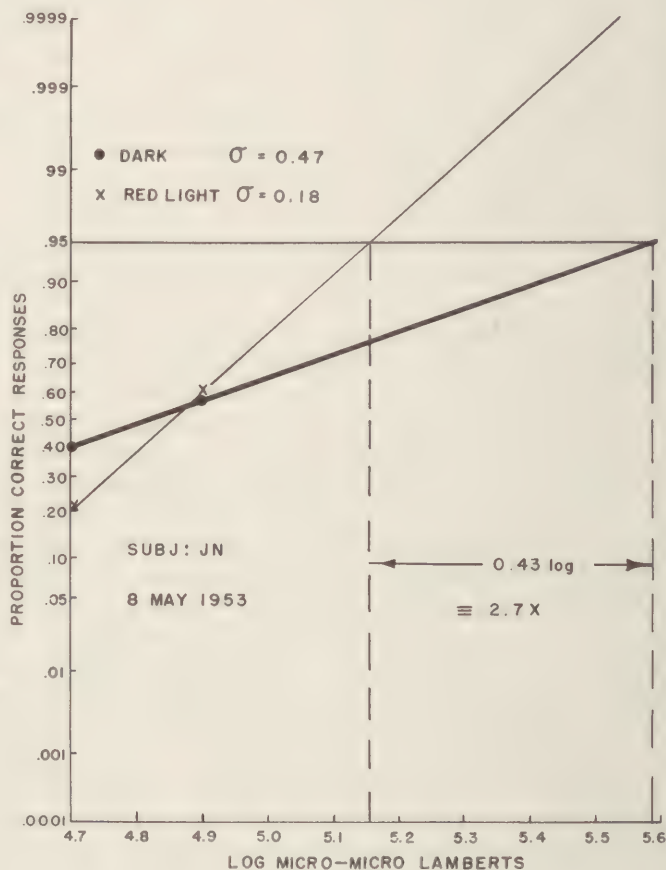
D. State of Adaptation of the Eye at the Start of the Exposure Period

The results obtained by Miles[9] in Experiment Ic (where high-brightness pre-adaptation was omitted), the relatively large magnitude of photosensitization reported by the British investigators[4] (where pre-adaptation was to only seven ft-c), as well as the findings of Aubert,[1] of Helmholtz,[2] and of Kravkov and Semenovskaya,[3] indicate that the phenomenon here under consideration is more pronounced when the eye is not adapted to a high brightness at the start of the exposure period.

E. Summary

The phenomenon reported by Aubert,[1] by Helmholtz,[2] by Kravkov and Semenovskaya,[3] by the British experimenters,[4,5] by Miles,[8,9] and by the present writer[16,19] has for many years been ignored or discredited. The experimental evidence now available would appear to render such a conclusion no longer tenable. It may be noted, in particular, that the negative reports of Lee,[12] of Schoen and Dimmick,[14] of Mitchell, Morris, and Dimmick,[15] and of Smith and Dimmick[17] have consisted merely of categorical denials of all conflicting evidence on the basis of, at best, single experiments.

Moreover, the rejection of all positive findings would by no means eliminate all the discrepancies in published experimental results, since the various sets of negative findings do not agree one with another. For example, Mitchell, Morris, and Dimmick report considerably higher thresholds following red light than following total darkness, whereas the most recent report on this subject from the New London laboratory—that of Smith and Dimmick—shows no significant difference between the two exposure conditions. Another case in point is the disagreement between Lee and the Smith-Dimmick findings with regard to the effect of red light on the variability of response.

It would therefore appear that the hypothesis advanced above is correct, and that the several independent reports of apparent visual photosensitization[1-5,8,9,16,19] are in accord with experimental observation.

III. CONCLUSIONS

1. Certain conditions of visual excitation during the course of dark adaptation are associated with latent changes in the brightness threshold and/or in the variability of response. These changes are manifested, under appropriate experimental conditions, as a phenomenon of apparent visual photosensitization.

2. Red light is more effective than white light in mediating this phenomenon, but this observation does not appear to be definitive of the wavelength-sensitivity of the phenomenon.

3. The effect is more pronounced when the eye is not adapted to a high brightness at the start of the exposure period.

4. Since contra-lateral exposure appears to be effective in mediating this effect, it is to be doubted that the phenomenon proceeds independently in the two eyes to the extent that ordinary visual dark adaptation does.

5. The phenomenon is of theoretical significance and of practical value, but appreciation of the former and utilization of the latter must await a fuller knowledge of the experimental conditions which are most closely associated with its appearance.

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RELATIVE PRECISION OF RANGE INFORMATION OBTAINABLE WITH FIXED BALLISTIC AND WANDER-MARK STEREOSCOPIC RETICLES

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INTRODUCTION

The ballistic or Zaroodny (7) stereoscopic range-finding sight represents a modification of the fixed reticle stereoscopic range finder, patented by Zeiss in 1893 (Gleichen, 2, p. 204). In the original instrument, a fixed reticle recedes in depth in a snake-fence pattern. Range is estimated by comparing the distance to the target with known distance points on the reticle. In the ballistic modification, the stereoscopic principle is utilized to generate in the reticle space a pattern similar to a shell trajectory (Figure 1). This pattern is generated by combining in the reticle the vergence angle for selected distances with the angle of gun elevation necessary to bring the point of shell strike to these distances. Angles of gun elevation appear in the reticle pattern as angles of depression. Stereoscopic contact between a target and the appropriate point on the trajectory portrayed in the reticle is made by elevating or depressing the sight.

SCHEMATIC REPRESENTATION OF THE SUBJECTIVE APPEARANCE OF THE BALLISTIC RETICLE

Figure 1

Certain liberties with actual fact have been taken in Figure 1 in order to convey the subjective impression this reticle gives when viewed binocularly. Geometrically, a side view of the reticle space superimposed on the target space should show the reticle elements at equal linear intervals from the observer. Subjectively, when viewed from the point of origin, each dot is seen nearer in depth to the next preceding dot, until finally, at the far ranges, there is almost no apparent depth difference between the dots. This has been portrayed in Figure 1 by the unequal spacing of the dots.

Interest in such a reticle as a gun-controlling sight gives rise to the following questions: "What level of precision can be attained by experienced observers with this form of stereoscopic reticle?" "What level of precision can be attained by naive observers with this form of reticle with a minimum of training?" and "Does the ballistic curvature of the reticle affect its sensitivity, or lead to shifts in mean error with distance?"

DESCRIPTION OF THE INSTRUMENTS

The instruments used in this study were Navy Mark 63 stereoscopic range finders modified by Frankford Arsenal (4). One (Serial No. 65) contained the ballistic reticle and the comparison instrument (Serial No. 8) contained the Army "V" wander-mark reticle. Both instruments were mounted on their navy pedestal mounts which allowed the range finders to be adjusted in azimuth and elevation. The range finder (Serial No. 65) which mounted the ballistic reticle was further modified, as shown in Figure 2.
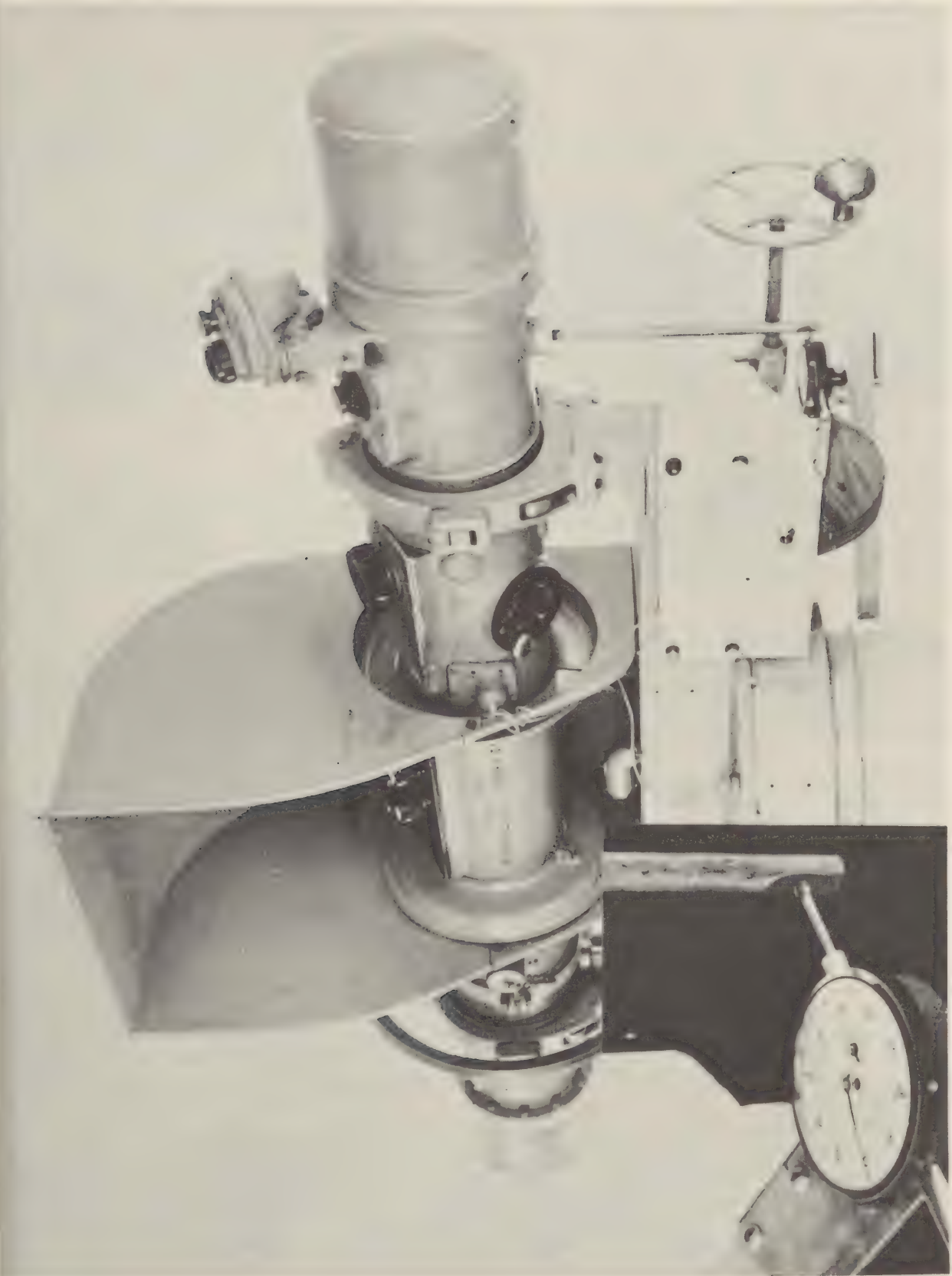
80

Figure 2

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The helium-charging cover cap, located on the bottom of the range-finder body tube directly under the trainer's telescope, was removed and replaced by a similar threaded brass cap, from which extended downward a brass rod one-half inch in diameter and ten inches in length. This rod contacted the plunger of a one-inch movement dial gauge which was mounted on a steel plate bolted to the right side of the mount. Rotation of the range-finder tube to elevate or depress the reticle in relation to the target field resulted in an angular displacement of the rod. This displacement was measured tangentially by the dial gauge to the .0005 inch.

METHOD AND PROCEDURE

The task of accumulating data with the ballistic sight poses several problems. The obtaining of repeat measures on a given target is complicated by the fact that, unless the apparent range of the reticle in relation to the target can be changed from reading to reading, the observer is very likely to produce a series of identical ranges. In the work of this study, the range-compensating mechanism of the range finder was systematically changed from reading to reading by the experimenter, above and below a reference value of 2000 yards (4). The reticle was thus displaced in depth by an equivalent angle and the apparent range to the target correspondingly changed.

The range significance of the elevation measures once obtained is complicated by characteristics of the target. Elevation measures are composed of an angle of site, an angle of super-elevation appropriate to the target range, and an angle of aiming point error. Thus, targets with a clearly defined aiming point, as well as a particular range, are needed. For this reason, chimney and roof-top targets which gave clear horizontal edges were chosen.

In evaluating the effect of the ballistic curvature of the reticle, a single target, C/C, was used to control for effects of background and immediate surround. By adjusting the range-compensating mechanism to 885, 1130, and 2900 yards, relative range of the target was shifted to permit the use of three portions of the reticle: the near and flat, the mid-range moderately curving, and the far-range steeply curving.

Stereoscopic contact with the ballistic reticle was obtained by placing the reticle immediately to the left of the target and elevating the range finder until the trajectory of the reticle pattern was seen to pass by the aiming point of the target. Attention was directed to the target and that portion of the reticle in its depth vicinity. Double images of portions of the reticle frequently occurred as a result of contact with features of the terrain and inability of the observer to simultaneously fuse the complete depth of the reticle. Stereoscopic contact with the wander-mark reticle was obtained in the usual manner by manipulation of the range knob to "fly" the reticle to apparent depth equality with the target.

Targets

The three targets used in obtaining the data of this study are visible in Figure 3 taken from the ranging position located on the laboratory roof approximately 30 feet above the ground. The line of sight to the targets are level or slightly depressed, due to angle of site differences.

The nearest target, Vent, is a small, peaked-roof, wooden ventilator on the barracks building in the left-center foreground. The target is characterized by a clear foreground, with considerable vertical intercept on the side and roof of the building. The space behind the vent is relatively deep, terminating in a background of barracks roofs at various angles and ranges. The range to the target is 779 yards by triangulation.

The furthest distant target, B/C, is a large brick chimney in the center background. The target is characterized by a foreground cluttered with barracks sides, roofs, and

chimneys below the level of the target, and a terrestrial background approximately 4000 yards distant. There is minimal interference from other objects of equal height in the immediate vicinity. The range to the target is 2083 yards by triangulation.

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Figure 3

The third target, C/C, was a lone chimney at mid-range in the right middle ground with good depth on all sides. This chimney was used for calibration of the reticle, and served as reference target for angle of sight determinations. The range of the target is 916 yards by triangulation.

Subjects

The experienced observers used in obtaining the data of this test were two civilian staff members and three enlisted assistants from the laboratory. These individuals had all had considerable stereoscopic ranging experience, both with laboratory instruments and in the field. The naive observers were Class A profile men from the training division who had completed their basic training and were waiting orders.

These observers were handled in three groups. One group, which consisted of the experienced observers, was used in all phases of the test. A second group, which consisted of ten naive observers selected from 26 men from the training division, were used to obtain the data with the wander-mark reticle. The third group, which consisted of 15 observers selected from 22 men from the training division, were trained with the ballistic reticle only. Half of the group of ten naive observers who used the wander-mark reticle had previously worked with the ballistic reticle. The group of 15 naive observers who were trained on the ballistic reticle had no previous stereoscopic ranging experience. All of the naive men were screened on the Bausch and Lomb Ortho-rater, and a few who were functionally monocular were eliminated. Further selection was accomplished with the range finder in terms of the ability of the observer to "see stereo" with the limited amount of training given.

Data Collection and Training

The data collected were of two types: wander-mark, stereo-contact range scale readings in yards, and range-finder tube elevation in "dial" units. Data were taken only on those days which provided sufficient sunlight to cast a sharp shadow. Experimental sessions were held between the hours of 1230 and 1500, to obtain constant front lighting of the targets. The morning hours were used for training.

For the experienced observers, the wander-mark range data were obtained in sequences of twenty successive settings each on the vent and B/C. The ballistic elevation

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data were obtained in random-order sequences across five target and range-compensating mechanism combinations. The effect of this procedure was to intersperse four unrelated range settings between each successive setting on any one target. Twenty settings were accumulated on each target combination. Prior to the actual taking of data, seven similar training sessions were given. Four of the training sessions utilized a different assortment of targets.

The data for the naive observers were obtained in single session following a morning practice period. The random-order procedure used with the ballistic reticle for the experienced observers was used with the naive observers for both the wander-mark and the ballistic reticle. This seemed necessary to assure that their settings with the wander-mark reticle were truly stereoscopic.

RESULTS AND DISCUSSIONS

Much as the original data were obtained in yards with the wander-mark reticle and in dial units of elevation with the ballistic reticle, all of the data have been transformed through non-linear, ballistic, and parallactic angle transformations to seconds of arc in the ranging triangle and mils elevations at the gun. Since the Mark 63 (5) range finder is an eight-power instrument, 12 seconds of arc at the eye, or one unit of error, is 1.5 seconds of parallactic angle in the ranging triangle.

Figure 4 presents a summary of the average standard deviation by group for each reticle on the targets, Vent and B/C. The standard deviations of which these are the averages were based on 20 range settings per observer per target.

It is apparent from the top row of figures in Figure 4 that the experienced observers utilized the wander-mark instrument at very nearly the expected capability limit of one U.O.E. It is also interesting to note that the average standard deviation for the Vent at 779 yards is not significantly dif-

SUMMARY OF AVERAGE STANDARD DEVIATIONS

| | | | TARGETS | |
| | | VENT - 779 yds. | | B/C - 2083 yds. |
		∠ in seconds	mils elevation	∠ in seconds	mils elevation
EXPERIENCED OBSERVERS					
wandermark	N=5	1.9	.04	1.7	.18
ballistic		10.1	.14	5.5	.55
NAIVE OBSERVERS					
wandermark	N=10	4.4	.05	5.0	.42
ballistic	N=15	16.3	.15	4.3	.42

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Figure 4

ferent from the average standard deviation obtained on B/C at 2083 yards. The probability level of this difference is .90, "t" equals .06. The same is true for the naive observers at the .20 level of probability, "t" equals 1.13.

The naive observers are clearly distinct from the experienced observers. They differ in mean as shown by the values in the table and in the group variance. Group variances for columns 1 and 3 are, for the experienced observers, .18 and .55 seconds of arc squared; and for the naive observers, 5.26 and 5.33 seconds of arc squared. There is overlap between the two groups in the measures of only two individuals.

Note the shift in the value of the standard deviations in mils with range. The change from .04 to .18 mils and from .05 to .42 mils is indicative of the non-linear relation of parallactic angle in the ranging triangle to elevation at the gun.

Statistical test of the difference by column between the average standard deviations of the experienced and naive observers with the ballistic reticle indicate no significant

differences. The influence of past experience with stereoscopic instruments is not apparent in this feature of the observed performance. The proficiency difference shown by the values of column 1 is due to one highly divergent naive observer.

The standard deviations obtained with the ballistic reticle at the near range are larger for all subjects, experienced and naive, than those obtained at the far range. The explanation for this may lie entirely in the ballistic transformation of the data. The trajectory of the reticle is flat in the near portions, and small errors of elevation are magnified by the mathematical transformation.

A psychological explanation can also be given for the larger standard deviations at the near ranges. When an observer makes a setting, he must interpolate the trajectory between the reticle elements. His ability in the near portions of the reticle where the reticle elements are widely separated in apparent depth may possibly suffer for the lack of proximal reticle points.

The reverse trend with target range of the ballistic standard deviation data, when expressed in mils as compared with parallactic angle, suggests that the data are actually not linear in either measure. This is consistent with the complex psychological task of the ballistic reticle which combines a vertical vernier alignment and a stereoscopic depth judgment.

In view of the uncertainty as to the appropriate explanation of the influence of distance upon the standard deviation data obtained with the ballistic reticle, the comparison between the wander-mark and ballistic reticles will be made only at the longer range. The standard deviations obtained for the experienced observers with the wander-mark and ballistic reticles on the B/C target differ in mean, as shown by the values of column 3, and in group variance. The group variances for the wander-mark reticle and the ballistic reticle are .55 and 4.76 seconds of arc squared. The corresponding difference in the performance of the naive observers with the wander-mark and the ballistic reticles is not significant at the .90 level of probability, "t" equals .08.

A summary of the average mean error by group and target with each reticle is given in Figure 5. These data can be considered only in relative terms, as the Internal Corrector Setting of the range finders were constant for all observers and there is no certainty of the linearity of the data with range in view of the standard deviation data just reported.

A consideration of the values of columns 1 and 2 indicates that both naive and experienced observers, irrespective of reticle, ranged the far target in error more posi-

SUMMARY OF AVERAGE MEAN ERRORS
(seconds of parallactic angle)

		TARGETS			
	vent 779 yds.	b/c 2083 yds.	c/c -2900 802 yds.	c/c -1130 1415 yds.	c/c -885 2166 yds.
EXPERIENCED OBSERVERS					
wandermark N=5	-14.1	-8.6			
ballistic	-14.5	5.9	-11.6	-6.0	-.9
NAIVE OBSERVERS					
wandermark N=10	-13.0	-7.8			
ballistic N=15	-33.9	4.6	-34.0	-14.2	-1.6

ARMY MEDICAL RESEARCH LABORATORY
FORT KNOX KENTUCKY

Figure 5

tively than the near target. For the ballistic reticle, this shift of mean error is apparently a function of the reticle as the same trend is present in the data of the columns C/C-2900 and C/C-885 which were taken on a single target. A frequency count for all observers of the occurrence of this phenomenon indicates that the mean error is increasingly more positive with distance with the wander-mark reticle for 11 of 15 observers. The binomial expansion probability for 11 or more out of 15 by chance is .05. For the

ballistic reticle, the count is 16 of 20 observers, a probability of .002, and for the ballistic reticle on target C/C-2900 and C/C-885 the count is 18 of 20 observers, a probability of .0001.

An explanation of these data for the wander-mark reticle is possible in terms of a systematic error in the interocular setting of the instrument (6), an error in the triangulated range of one or both of the targets, or subjective displacement of the target due to aerial perspective and loss of target-to-background contrast with distance, a phenomenon demonstrated by Dr. G. A. Fry (1) in research conducted for the NDRC during the last war.

The same factors which might give rise to the phenomenon with the wander-mark reticle are operative with the ballistic reticle. In addition, there is the possibility of a rotational error in the installation of the reticle blanks (4), and a psychological error arising from the construction of the reticle. A three-second rotational error was known to be present, the direction of which conforms with the phenomenon, but this falls far short of the observed magnitude. The psychological explanation is in terms of the strength of the disparity cue relative to the size cue as a function of the separation between objects. If one considers the construction of the reticle, these facts are apparent: The retinal subtense of the reticle elements is constant irrespective of their binocular disparity, and, consistent with the ballistic properties of the ammunition, the vertical displacement of the reticle elements is increased as their binocular disparity is increased. This gives rise in the reticle, as shown in Figure 1, to the dots at near ranges having less vertical separation and greater depth separation than those dots at far ranges.

Experimentation conducted at the Army Medical Research Laboratory (3) has demonstrated a tendency for retinal subtense to be more effective in determining relative depth between objects with increase in lateral separation. Generalizing this finding to the ballistic reticle, the prediction would be that the more distant elements of the reticle would foreshorten in depth relative to the near-distant elements, giving rise to positively increasing errors with distance. Unfortunately, the uncertainty of measurement and curvalinearity apparently present in the data does not permit a definitive test of the prediction.

SUMMARY

To summarize, our work with the ballistic reticle has indicated that the standard deviation sensitivity in parallactic angle increases as a function of distance, probably in part due to the relative depth separation of the reticle elements. The reticle, as designed, requires an increasingly more negative Internal Corrector adjustment with increasing range. This tendency is possibly attributable to the use of reticle elements of constant retinal subtense.

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VISIBILITY AND USES OF SELF-LUMINOUS MARKERS

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During World War II and in the Korean struggle, phosphors excited to luminescence by radium salts were used by the armed services as markers. These radium-excited markers were limited in their usefulness because the maximum luminance value obtainable without deterioration of the phosphor was about 20 "effective" microlamberts. Also, the color range of these radium markers was restricted to a relatively narrow portion of the visible spectrum.

In the last four years, experimental work has been performed on the development of a self-luminous marker excited by the radioisotope strontium-90. This radioisotope with a half-life of 25 years decays with the emission of a beta particle which is sufficiently energetic to excite certain phosphors to luminance values as high as 100 "effective" microlamberts. Also, a range of colors from blue to red-orange is now available to the armed forces.

Since heterochromatic photometric measurements must be performed on these colored sources in the mesopic region, it is necessary to specify the measuring procedure and the type photometer to be employed. It is generally agreed that the photometric field should be split vertically rather than horizontally. This follows from some evidence[1] that the left and right halves of the eye are more nearly symmetrical than the upper and lower halves. The photometric field should subtend at least ten degrees at the observer's eye. Reeves[2] showed in 1917 that luminances measured with fields smaller than 5° are dependent upon the field size used. It is also necessary that the observer be well dark-adapted and that he view the photometer field long enough to become adapted to the luminance level of interest. A standard tungsten lamp operated at a color temperature of 2360° K has been used extensively in Purkinje photometry, and the "effective" microlambert has been defined as the unit of luminance produced by this standard. However, in view of other laboratories having adopted the 2042° K source as a standard for low-level photometric work, it is inevitable that the Naval Research Laboratory follow suit sometime in the near future.

The spectral sensitivity curve of the human eye at adaptation levels in the mesopic region have been interpolated from the photopic and scotopic curves. It is possible to correct a multiplier phototube with a filter to match this sensitivity curve at a given adaptation level. When this detector has been calibrated to read luminance values corresponding to the average results of a number of visual observers, the detector becomes a physical photometer at this adaptation level. Each measurement made with this physical photometer gives the average of 25 visual observations as is explained later.

Figure 1 shows the instrument used to calibrate the detector. S is a standard tungsten lamp which produces any desired luminance value in "effective" microlamberts on a piece of opal glass adjacent to one-half of the photometer cube B. E is a colored source composed of another tungsten lamp and a Corning filter. This colored light is reflected to the other half of the photometer cube by mirror M. The observer O makes a luminance match by varying the distance between S and the photometer cube. After having made 5 settings of S, an operator turns the mirror M so as to reflect the colored light E to the detector P and the output current is noted. The distance between E and B is then changed and a new set of readings on S is determined. A calibration lamp C kept at

1. P. C. Livingston, The Lancet, 8 July and 15 July 1944.
2. P. Reeves, J. Opt. Soc. Amer., 1, 148 (1917).

constant voltage sets the gain of the detector at a constant value from one day to the next. An observer usually makes one run in which he makes luminance matches from 0.1 to 100 "effective" microlamberts for a given color. Luminance is then plotted against output current. The final calibration curve for a given color is determined from the average results of five observers. These five observers calibrate the detector in the same manner for different colored sources E throughout the visible spectrum. Figure 2 shows such a set of calibration curves for a detector which was corrected to match the eye at approximately 12 "effective" microlamberts. It is evident from the curves that the variation in luminance value determined in this region would not be strongly dependent upon its color. Other detectors have been calibrated in the same manner for other adaptation levels in the mesopic region. Details of this photometer and its performance have been reported.[3]
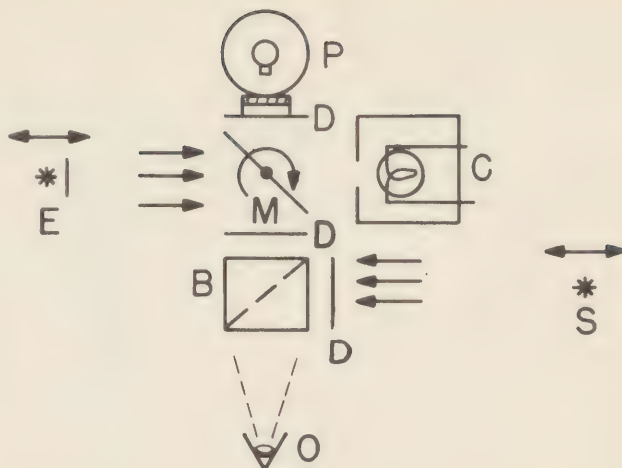
Figure 1

Knowing the luminance values of these low-level light sources, it is possible to make threshold visibility measurements on them. The maximum distance at which these sources are visible is a function of marker size, luminance, color and background contrast in addition to the adaptation state of the observer's eye and the viewing method which he uses.

Visibility measurements were performed with the self-luminous marker attached in the center of a board 2 feet square painted flat black. The observer walked toward the target until he could see it with approximately 90 per cent certainty. Figure 3 shows the average results of 3 observers who were instructed to use extrafoveal vision on colored markers 1-3/4 inches in diameter. It is to be noted that for a given luminance, the green and blue markers were visible at a greater distance than the red and orange ones. Figure 4 shows similar results for observers who were instructed to use foveal vision. Visible ranges were determined to be less for foveal than for extrafoveal vision for all colors although the difference is not as great for red as for green sources. In Figure 5, visible ranges are plotted against marker diameter for different colored sources of various luminance values. This figure shows that for a given luminance the maximum visible distance is a linear function of the angle subtended by the target at the observer's eye.

In the measurements given above, the angle subtended by the target was a variable. Usually, threshold measurements are made with this angle held constant for a given series of measurements. The contrast threshold between background and source is then determined for different values of background luminance. Knoll, Tousey and Hulburt[4] have reported results using white light as a source in threshold measurements. Their results are shown in Figure 6 with a comparison of green and red markers as indicated. These deviations of the red and green values from the curve of Knoll et al may be explained by the variation in retinal sensitivity for different colors as a function of angular distance from the fovea, and the fact that photometric measurements were made with a 12 degree field while the visibility measurements were made with a field less than 1 minute of arc.

The trichromatic coefficients of the colored markers used have been plotted in the chromaticity diagram shown as Figure 7. The solid point may be disregarded in this paper.

3. W. S. Plymale, Jr. and G. T. Hicks, J. Opt. Soc. Amer., 42, 344 (1952).
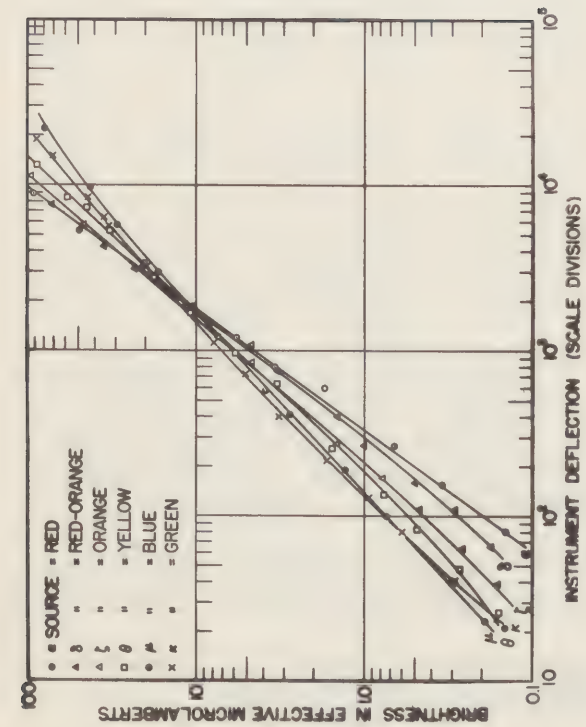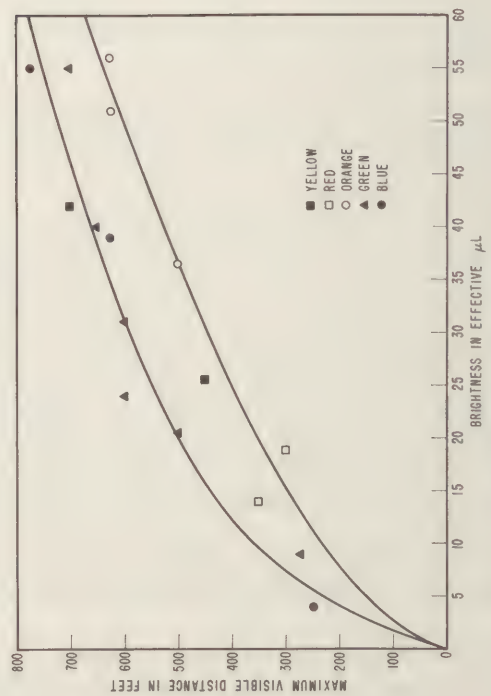4. H. A. Knoll, R. Tousey, and E. O. Hulburt, J. Opt. Soc. Amer., 36, 480 (1946).

Figure 3

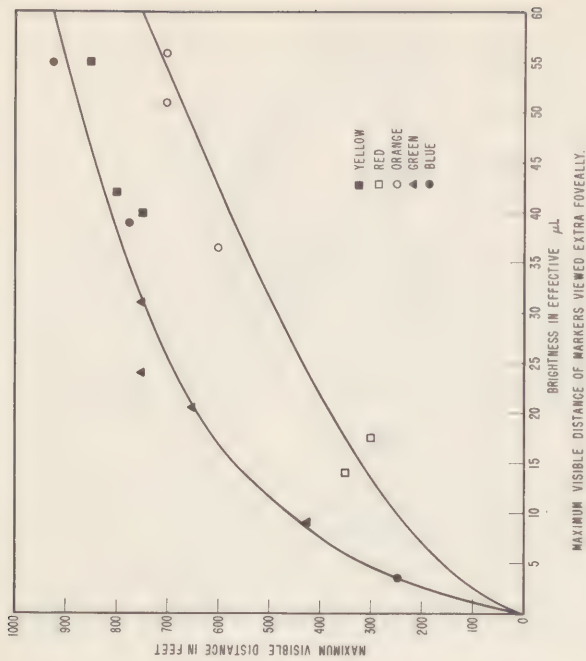MAXIMUM VISIBLE DISTANCE IN FEET

MAXIMUM VISIBLE DISTANCE OF MARKERS VIEWED EXTRA FOVEALLY.

BRIGHTNESS IN EFFECTIVE μL

■ YELLOW
□ RED
○ ORANGE
▲ GREEN
● BLUE

Figure 5

DIAMETER OF LUMINOUS SURFACE IN INCHES

MAXIMUM VISIBLE DISTANCE OF MARKERS WITH VARIOUS DIAMETERS

MAXIMUM VISIBLE DISTANCE IN FEET

■ - $\beta = 40\ \mu L$ - YELLOW
□ - $\beta = 17.5\ \mu L$ - RED
○ - $\beta = 51.0\ \mu L$ - ORANGE
▲ - $\beta \approx 5\ \mu L$ - GREEN

Figure 2

BRIGHTNESS IN EFFECTIVE MICROLAMBERTS

INSTRUMENT DEFLECTION (SCALE DIVISIONS)

SOURCE = RED
" = RED-ORANGE
" = ORANGE
" = YELLOW
" = BLUE
" = GREEN

Figure 4

MAXIMUM VISIBLE DISTANCE IN FEET

MAXIMUM VISIBLE DISTANCE OF MARKERS VIEWED FOVEALLY

BRIGHTNESS IN EFFECTIVE μL

■ YELLOW
□ RED
○ ORANGE
▲ GREEN
● BLUE
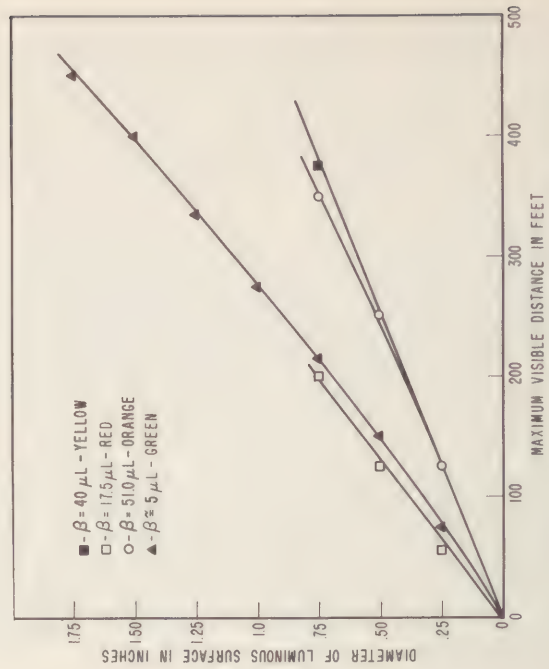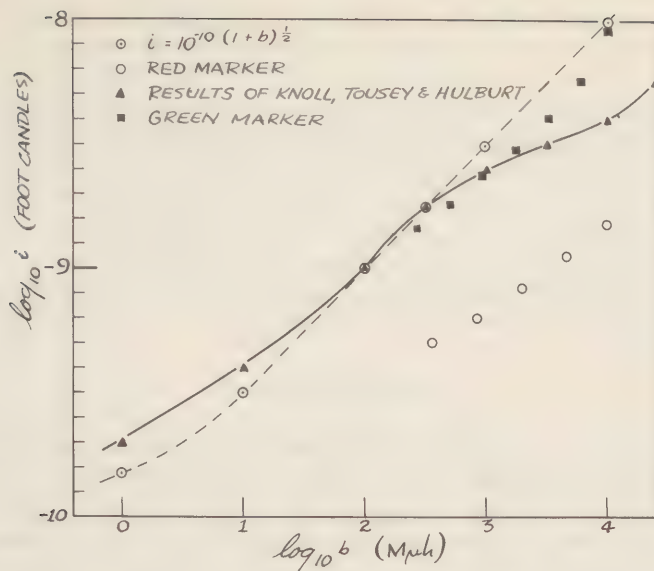
Figure 6

Markers of one color only have been used in the past as personnel and deck markers by the Navy. Other units of the armed forces have used them to mark vehicles, bridges, trails, and buildings. These new colored markers offer more possible uses. [5] These uses may be briefly summarized as follow:

1. To mark different types of ammunition racks in ready boxes.

2. Personnel identification is made easier through the use of color.

3. The logistics of an amphibious operation was simplified during World War II by using unit color identification. Colored markers extend this simplification through the hours of darkness.

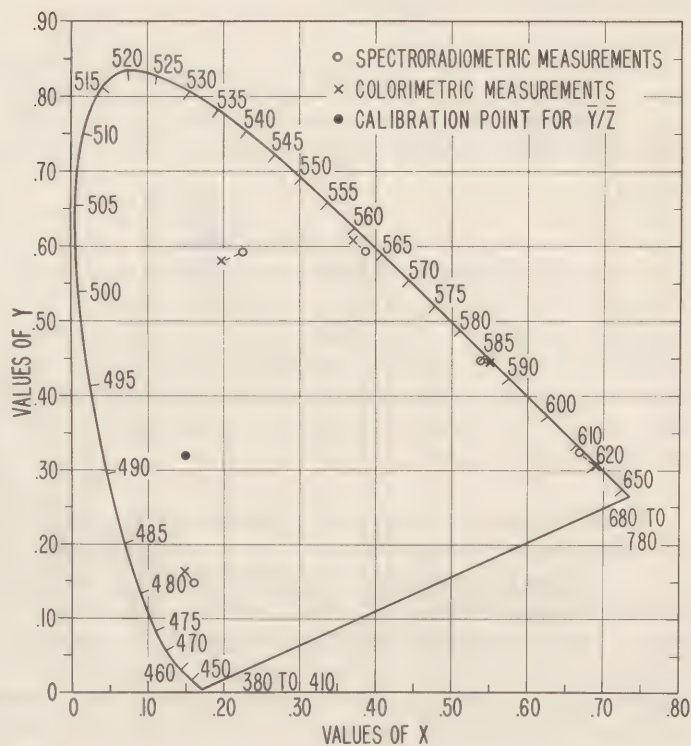4. Underwater Demolition Teams may use them as light sources.

Figure 7

5. G. T. Hicks et al NRL Report No. 4192, 23 June 1953.

THE DISTRIBUTION OF INSTRUMENTAL DIOPTER SETTINGS IN THE ARMY POPULATION AND THEIR RELATION TO PERTINENT VISUAL VARIABLES

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INTRODUCTION

Many items of military optical equipment have dioptric adjustments incorporated into them so that the user may adjust the focus of the instrument to fit the refractive conditions of his eyes. Such instruments as the more recent models of tank telescopes and periscopes binoculars and stereoscopic range finders have these diopter adjustments available to the user. Associated with the use of these diopter scales is the proper method of adjustment to be used by the observer, and the effect of any "improper" adjustments which he may make. Since these diopter scale measures also offer a crude index of the visual acuity of the observer, the distribution of these measures and their relationship to other visual variables are also of interest.

PURPOSE

The purpose of this study is to describe the distribution of instrumental diopter settings and their relationship to visual skills and visual performance variables.

SUBJECTS AND APPARATUS

Subjects for the study were 116 Army enlisted men who had just completed 16 weeks of basic military training. The average age of the group was 21.0 years, with a standard deviation of 2.5. The mean Army Classification Battery Aptitude Area I score for the group was 95.8, with a standard deviation of 21.3 (Aptitude Area I is a measure of general intelligence or of ability to be trained; within the Army as a whole, the mean value is said to be 100, with a standard deviation of 20). Of the total group, 94 were Caucasian and 22 were Negroid.

All diopter measures reported were made on floor-mounted models of the tank stereoscopic Range Finder T41. This range finder is part of the fire control system of the U.S. Medium Tank M47.[1] This instrument has a base length of 60 inches and a magnification power of 7.5. It has an interpupillary distance adjustment, and also has on each eyepiece a diopter adjustment which ranges from slightly less than minus three to slightly more than plus three diopters. Other instruments used in testing the subjects included the Bausch & Lomb Ortho-Rater, the Howard-Dolman Depth Perception Test, the Keystone Aviators Unit Stereopsis Test, and the Stereoptometer.[1]

PROCEDURE

All subjects were tested on the visual measures listed above prior to their undertaking any instruction or practice on the range finder.

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1. The Stereoptometer was developed by Dr. George S. Harker and his associates at the Army Medical Research Laboratory, Fort Knox, Kentucky. All of the vision testing instruments were used through the courtesy of that research facility.

The mean of ten trials per subject on the U.S. Navy Interpupillometer, Mark 1, was used as each subject's interpupillary distance setting on the range finder. Before subjects began ranging practice, each subject adjusted the diopter scale for each eye separately, manipulating the scale for each eye until the point of clearest vision was reached. For most subjects, this adjustment technique involved exploring the entire diopter scale, bracketing the point of clearest vision, and finally, settling upon this point between the unclear regions on either side. Each man then recorded this diopter scale reading and retained it for the next five weeks of range finder drill.

Any relationships reported here between range finder proficiency and diopter settings were from range settings made on a target 1965 yards away from the observers.

<div align="center">RESULTS</div>

The distribution of the diopter settings for each eye of the 116 subjects is shown in Figure 1. It will be seen that the modal value for each eye is the class interval, -.75 to -1.24 diopters. The mean for the right eye diopter settings is -1.36, and that for the left eye is -1.23 diopters. Only about eight per cent of the settings were zero or plus settings.

DISTRIBUTION OF DIOPTER SETTINGS MADE BY MEN USING THE RANGE FINDER, T41.
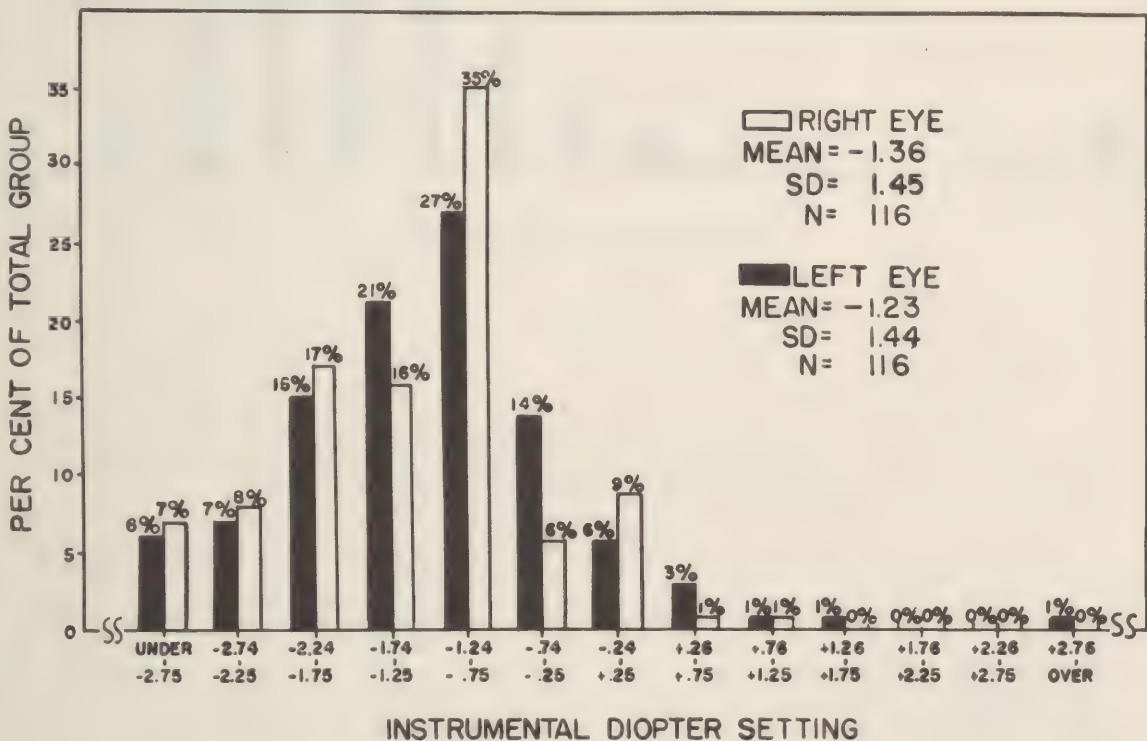

Figure 1

It is of interest to contrast the distribution of instrumental diopter settings with Ortho-Rater far acuity test scores for each eye as shown in Figure 2. The mean score for right eye far acuity is 10.78, and that for the left eye, 9.91. These means correspond roughly to Snellen fraction notations of 20/19 and 20/20 for the right and left eyes, respectively.

Coefficients of correlation of instrumental diopter settings with Ortho-Rater acuity scores, as well as with several measures of depth perception, are shown in Table 1.

<div align="center">93</div>

None of these correlations is statistically significant with the exception of far and near acuity measures for the left eye. These two statistically significant positive correlations indicate that high minus diopter settings are associated with good acuity scores at both far and near distances.
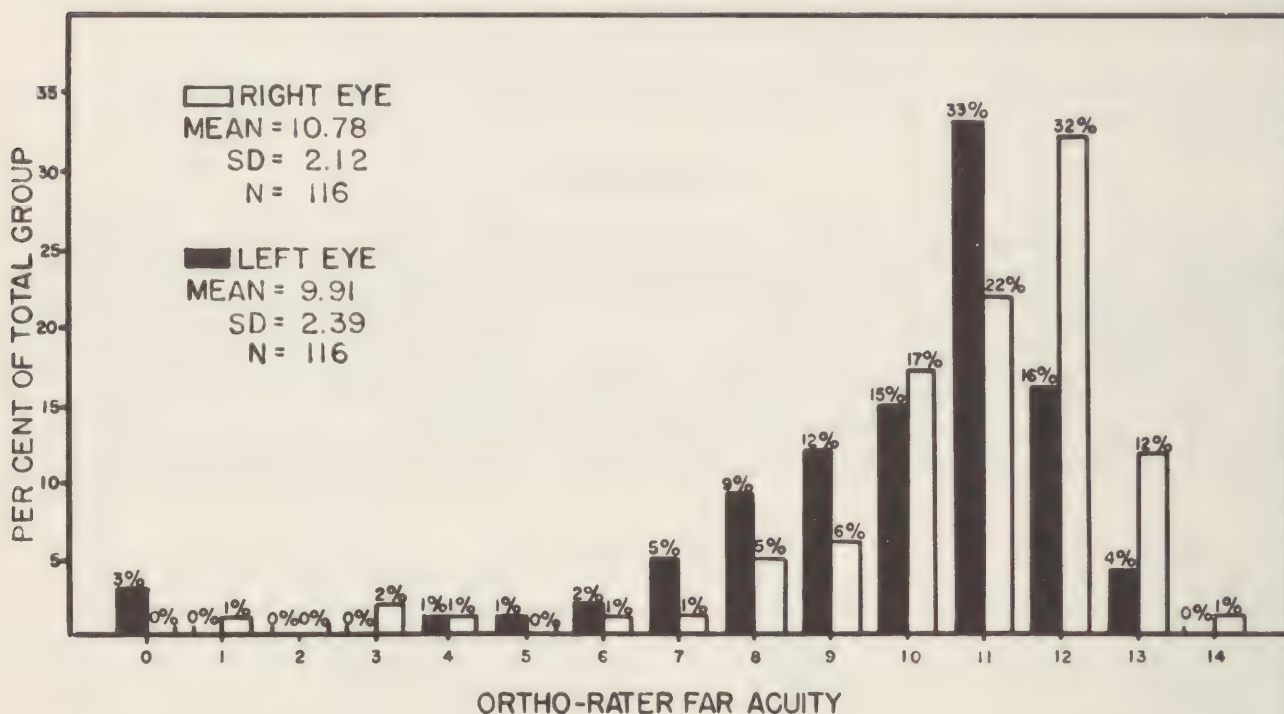
DISTRIBUTION OF ORTHO-RATER FAR ACUITY SCORES

Figure 2

Table 1

COEFFICIENTS OF CORRELATION BETWEEN INSTRUMENTAL DIOPTER SETTINGS AND SEVERAL OTHER VISION MEASURES

Vision Test	Correlation with Diopter Settings	
	Right	Left
Ortho-Rater		
Far Acuity - Right	.03	-.04
Far Acuity - Left	-.02	.21[a]
Far Stereopsis	.00	.12
Near Acuity - Right	.10	.16
Near Acuity - Left	-.05	.25[b]
Stereoptometer		
Mean of 12 Trials	-.07	-.04
SD of 12 Trials	-.08	-.13
Howard-Dolman Depth Perception Test		
Mean of 12 Trials	.05	-.06
SD of 12 Trials	.06	.12
Mean Error of 12 Trials	.00	-.01
Keystone Aviators Unit Depth Test	.13	.16
	(N = 116)	

[a]Significant at the 5 per cent level.   [b]Significant at the 1 per cent level.

Table 2 shows the coefficients of correlation between variability in ranging performance and the diopter adjustments which each subject made on the range finder. Three different kinds of diopter values have been used in these correlations: (1) the actual diopter value, (2) a "corrected" diopter value for far vision,[2] and (3) a "corrected" diopter value for near vision.[2] Diopter settings for the right eye are unrelated to ranging proficiency. "Corrected" diopter values for the left eye do show statistically significant relationship to ranging. These significant negative correlations show, in general, that the greater the difference between the correction needed and the correction actually used, the better the ranging performance of the subjects.

Table 2

COEFFICIENTS OF CORRELATION BETWEEN RANGE FINDING VARIABILITY
AND INSTRUMENTAL DIOPTER SETTINGS USED BY THE OBSERVERS

Diopter Value	Correlation With Range Setting Variability
Right Eye Diopter Setting	.05
Right Eye Diopter Setting minus "Correct" Setting for Far Acuity - Right	-.10
Right Eye Diopter Setting minus "Correct" Setting for Near Acuity - Right	-.05
Left Eye Diopter Setting	-.14
Left Eye Diopter Setting minus "Correct" Setting for Far Acuity - Left	-.28[a]
Left Eye Diopter Setting minus "Correct" Setting for Near Acuity - Left	-.32[b] (N = 110)

[a]Significant at the 5 per cent level.
[b]Significant at the 1 per cent level.

DISCUSSION

These results seem highly contradictory with respect to established ophthalmological and optometric practice. It would be expected that subjects' refractive error shown in visual acuity tests would be shown as well in instrumental diopter settings, and that the correlation between the two would be reasonably high. In this instance, however, it is not the case. In fact, when a significant correlation does appear, it is in the wrong direction, showing that minus correction increases as the level of visual acuity increases!

Two suggestions are offered to explain this result. First, visual acuity is high, not offering a wide range of values less than 10 (normal acuity). Hence, the results reported were obtained with a sample in which 75 to 80 per cent of the subjects had 20/20 or better

2. In computing the "corrected" value, it was assumed (1) that a zero diopter setting should be required with an Ortho-Rater acuity score of 10 (or 20/20 Snellen), (2) that minus corrections should be required for scores less than 10, and (3) that plus corrections should be required for scores higher than 10. The difference between an individual's actual setting and his "correct" setting was the value used for correlational purposes.

visual acuity. Ortho-Rater checkerboard-type acuity scores also may fail to pick out those men who had astigmatic errors, and these may be a source of error in the acuity scores. Second, the subjects were young, and their visual accommodative powers were good. They were permitted to adjust the setting in each eyepiece to the point of clearest vision, and it is possible that a very slight reduction in image size was sacrificed for crispness of definition and contrast, which a minus lens is said to offer.

The significant correlations between variability in ranging and left eye diopter correction are difficult to explain. The Range Finder T41 is an asymmetrical right converging range finder. In other words, the right eye reticle moves laterally to the right as targets are distant, and to the left as targets are close; the left eye reticle is stationary. But how this is related to dioptric adjustments is not known.

Research on range finders and height finders during World War II suggests that "unnecessary minus in the setting is automatically compensated for by additional accommodation effort, making it impossible for the observer to tell that the minus is excessive and hence leading to eyestrain for continued observation," (reference 2, p. 102). But in the present study, only two of the 116 men trained complained of visual fatigue or discomfort during the course of the five weeks of ranging practice; and good ranging performance (low variability) is associated with high minus diopter settings. The only explanation that can be offered for these statistically significant relationships is the suggestion that the stimulation of the accommodative apparatus (and the concomitant stimulation of convergence) serves to create a mild tension within the vision system which somehow has a facilitating effect upon those processes which contribute to a subject's judgment of depth.

The question now remains as to what the proper method of adjustment of the diopter scale should be. Current field manuals provide no specific instruction on this point, and leave the method of adjustment to the soldier. The common practice of observers seems to be to bracket the point of clearest vision. Some optometric and ophthalmological specialists might suggest, however, that it is better to err on the side of too much plus, rather than too much minus. Thus, it might be recommended that the diopter adjustment always be made from plus to minus, or that once the point of clear vision has been reached, a constant of .25 or .50 diopters be added in the plus direction. The results of this study do not seem to support this viewpoint, but suggest, rather, that the point of vision which is clearest to the subject (or possibly, additional minus) is a satisfactory setting.

SUMMARY AND CONCLUSIONS

Diopter settings, visual skills scores, and a sample of range finder performance data were collected on 116 Army enlisted men who had just completed 16 weeks of basic military training. The distribution of the diopter settings, and the coefficients of correlation between these settings and the visual skill and performance variables permit the following conclusions:

1. Instrumental diopter settings, made on the Range Finder T41 using a bracketing technique, focused upon a distant target, are predominantly minus settings with right and left eye mean values of -1.36 and -1.23, respectively.

2. Right eye diopter settings are not significantly related to visual acuity or to any of the depth perception measures on which the subjects were tested.

3. Left eye diopter settings are significantly correlated with left eye visual acuity at far and near distances, indicating that good acuity scores are associated with high minus settings.

4. "Corrected" left eye diopter settings are correlated significantly with ranging proficiency (variability scores), indicating that for left eye diopter settings, the greater the

differences between the correction needed and that actually used, the better the ranging performance of the subjects. The "corrected" right eye diopter settings did not show these relationships.

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Discussion

Dr. Harker questioned Mr. Olson concerning possible correlations between diopter settings and (a) optometric settings and (b) ICS settings.

Mr. Olson reported that such correlations had not been computed.

Dr. Spragg suggested that smaller range errors might have been obtained had adjustment been allowed in one direction only, rather than in both directions.

Dr. Fry emphasized that individuals differ in their basic relations between accommodation and convergence and that they should have been divided into suitable categories before data correlations were attempted.

A POSSIBLE APPLICATION OF VERNIER ACUITY
IN RIFLE MARKSMANSHIP

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On June 23, 1953, Mr. Howard C. Sarvis of New Meadows, Idaho, wrote a letter to President Eisenhower in which he suggested several ways of improving the effectiveness of rifle marksmanship in combat.[13]   One of Mr. Sarvis's suggestions was that the Army consider a new type of rifle sight which would involve the rifleman's use of vernier acuity. Subsequent evaluation of the Sarvis vernier acuity sight by the Human Resources Research Office, by direction of Army Field Forces, indicated that it was worth investigating.   At the present time, a few preliminary tests have been accomplished and others are being planned by HumRRO in conjunction with The Infantry School at Fort Benning, Georgia.

The present paper will discuss the vernier acuity sight as a possible application of known principles of visual acuity to the practical problem of obtaining accurate rifle fire in battle.   The following points will be briefly covered: (1) the visual task of the rifleman; (2) the structure and use of the vernier acuity sight and the standard M1 aperture-blade sight; (3) some experimental evidence upon which the superiority of the vernier acuity sight might be claimed; (4) the physiological theories which attempt to explain acuity data; and (5) a short summary of the preliminary field comparisons of the accuracy of the vernier acquity and M1 sights.

A necessary but not sufficient condition for the delivery of accurate rifle fire is the successful performance of a certain visual-motor task.   The rifleman must arrange himself and his weapon so that a straight line is formed by four points: his eye, a certain part of the rear sight, a certain part of the front sight and the target.   In training the rifleman,[17]   the Army divides this task into two subtasks: first, sight alignment, or the linear arrangement of the eye, the front and the rear sights; and secondly, sight picture, which is the addition of the target to the above-mentioned straight line by holding the aligned sights correctly on the target.   Of these two subtasks, sight alignment is more important than sight picture.   Since the sights are so much closer to the eye than they are to the target, a small error in sight alignment will change the strike of the bullet far more than will a similar error in sight picture.

The present U.S. Army rifle, the .30 caliber M1, employs a fixed blade or post as a front sight, and a movable aperture or peep-hole as a rear sight.   To obtain correct sight alignment with the M1, the blade of the front sight must be centered in the aperture of the rear sight; that is, an imaginary horizontal axis passing through the center of the rear sight must just touch the top of the front sight, and an imaginary vertical axis through the center of the rear sight must pass through the center of the front sight.   The correct sight picture is added by holding the front sight blade so that it appears to "just touch" the bottom of the target.   The vernier acuity sight, on the other hand, employs an inverted V as a front sight and an upright V as a rear sight.   Correct sight alignment of the vernier acuity sight is obtained by making an X of the two V's and the correct sight picture achieved by placing the center of the X on the target.

It may be mentioned in passing that one advantage claimed by Mr. Sarvis for the vernier acuity sight over the aperture sight is that the former would facilitate training in sight alignment.   The instruction "make an X" is probably easier to communicate than the complex directions, as mentioned above, about centering the blade in the aperture.   The

scope of the present paper, however, precludes further comparisons of the two sights on any but visual criteria.

Those experiments on visual acuity which seem to relate to the above-described visual-motor tasks of sight picture and sight alignment may be summarized as follows:

1. Sight picture
   a. M1 - The holding of the rifle so that the target just touches the front sight post seems to be akin to the often-measured discrimination of the minimum separable threshold.

   b. Sarvis - The holding of an X on a target has no immediately apparent analog in typical visual acuity tasks as measured in the laboratory.

2. Sight alignment
   a. M1 - The task of centering the post in the aperture also defies immediate laboratory parallel, but may be similar to psychophysical estimates or comparisons of distance in the lateral plane.

   b. Sarvis - The making of an X from two V's suggests a double vernier discrimination, since if a break can be recognized in either line of the X, the X is imperfect and the sights not aligned. It was from this feature of the sight-alignment task that Mr. Sarvis presumably chose the name "vernier acuity" for his sight, and claimed for it the advantages of the relatively low thresholds of vernier discriminations.

It is obvious, however, that none of the classical threshold experiments bears <u>directly</u> upon the relative ease or accuracy with which the above four tasks can be performed, for the reason that, in each case, the stimuli to be compared lie in different lateral planes. The discrimination of the "minimum separable" with the M1 involves the separation of the front sight and a target which may lie hundreds of yards away. Less damaging to extrapolative arguments but still notable is the similar fact that in the so-called double vernier discrimination in the alignment of the Sarvis sights, one-half of each of the lines which together comprise the X lies in a different lateral plane from the other half of the line. Thus predictions about the relative accuracy of the M1 and Sarvis sights drawn from typical laboratory data are necessarily complicated by the addition of a depth or accommodation factor. With this caution in mind, we may consider some experimentally established facts, which, though possibly pertinent to a comparison of the M1 and Sarvis sights, cannot be accepted as conclusive evidence in any sense.

Visual acuity is often defined as the ability to recognize the separation of two closely placed points or parallel lines. This <u>minimum separable</u> or <u>resolution threshold</u> is customarily expressed in terms of the visual angle subtended at the nodal point of the eye by the space between two objects situated at the minimum distance apart at which their duality can be recognized. The average human eye can resolve two points when the visual angle is one minute, or 60 seconds.[9] A minimum separable visual angle threshold of 44 seconds has been reported.[9]

<u>Vernier</u> acuity, on the other hand, is usually defined as the ability to discriminate a break in the contour of a border, a variation in the width of a line, or, more frequently, the misalignment of two straight lines laid end to end.[9, 10, 16] Vernier thresholds have been found to be much smaller than minimum separable thresholds. The following visual angles have been obtained in the measurement of thresholds of vernier acuity: 7 seconds by Stratton[14] in 1900, 3.7 seconds by Baker and Bryan[5] in 1912, and less than 2 seconds by Averill and Weymouth[4] in 1925. The discrimination implied by these threshold values is roughly equivalent to seeing a fly on a telephone pole half a mile away!

More recent experiments by Berry and others[6, 7] found that vernier acuity thresholds varied (a) from one second to seven seconds as the vertical separation between the misaligned test rods varied from 3.6 to 891 seconds of visual angle; and (b) from two seconds to seven seconds as field brightness was lowered from 192 to .07 millilamberts. They also found that the vernier threshold was apparently unaffected by the width of the test rod.[8]

The first attempts to explain physiologically the facts of minimum separable discrimination noted that the size of the retinal image for the minimum separable threshold was 4.4 microns and that the diameter of a foveal cone was from 2.5 to 4.0 microns. It was thus presumed that cone diameter was the limiting factor in discriminating two points or lines, or in other words, that the retinal image of one dot had to be separated from the image of another dot by at least one differently stimulated cone in order for their duality to be perceived. The reasoning behind this so-called "static" theory was the following: with an interspace of less than a cone's width, the two dots would fall upon a single cell, and from what is known of the nerve impulse, it could not be admitted that two parts of a visual receptor, upon receiving simultaneously the same type of stimulus, could give rise to dissimilar sensations.

Many difficulties stand in the way of so simple an explanation, not the least of which is the fact that the size and position of the retinal image cannot, owing to pupillary diffraction of light, be calculated with the precision required by the foregoing argument. Furthermore, the eye is constantly executing fine movements, hence the retinal image is constantly changing its position. Adler and Fliegelman[2] found that the average extent of the rapid tremor of the fixated eye was a little over two minutes of angular rotation, which is sufficient to move a point image over at least two to four cones.[1] Lord and Wright[11] subsequently reported that this tremor is considerably smaller than that stated by Adler, yet still large enough to shift a point image across two cones.

These eye movements, however, may account for the extraordinary accuracy of vernier acuity. Anderson and Weymouth[3, 15] suggest that as the retinal image shifts, causing successive stimulus patterns, the averaging of these patterns gives a sense of position which they call retinal local sign. Ratliff[12] recently obtained evidence that vernier acuity, as measured by a grating test object, is not assisted by eye movements, but he nevertheless concedes that these motions may aid in other types of vernier discriminations such as the perception of misalignment.

The relative accuracy of the M1 and Sarvis sights obviously cannot be decided solely from a consideration of the experimental and physiological literature in visual acuity. A field test involving actual firing at combat type targets is necessary. Thus far, the only completed comparisons have found that the M1 rifle equipped with the standard aperture sight produced a significantly greater number of hits than did the Sarvis sight rifles. These findings were not considered conclusive for two reasons: first, the experimental subjects, who fired with both sights, had had no experience with the Sarvis sight and a great deal of experience with the aperture sight--in fact, some of the subjects were reputed to be among the best M1 rifle shots in the U.S. Army. Secondly, the Sarvis sights were not properly made and attached, an unfortunate condition which resulted in such difficulties with the Sarvis equipped weapons as (a) the inability to zero them (b) movement of the front sight with each recoil, and (c) the falling off of several of the Sarvis sights after a day's firing, to the amusement of the not-unbiased subjects.

In conclusion, it may be reported that full-scale comparisons of the M1 and Sarvis sights, using naive subjects and well-built sights, are contemplated for the near future. Mr. Sarvis's sight may or may not be significantly more accurate than the aperture sight; on the basis of the currently available experimental and physiological evidence, such a field test seems to be the only way to find out.

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DISCUSSION

Dr. Uhlaner commented that AGO had performed a factorial analysis of vernier acuity and had found it to be similar to letter or checkerboard acuity.

Dr. Harker expressed interest in the use of a polaroid optical sight.

Dr. Hulburt questioned the effectiveness of the Sarvis sight at night.

Lt. Ramond expressed the opinion that the sight might be better at low luminances than a conventional sight because vernier acuity is less affected by low luminance than is visual acuity.

A PORTABLE LOW LEVEL LIGHTMETER

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It is the purpose of the lightmeter described in this paper to measure extremely low luminance levels (10^{-8} ft-L. threshold). The lightmeter is fully portable and the necessary power for the meter is supplied by a 6-volt wet battery (4.5A Load). Through a special circuitry, it was possible to achieve considerable reduction of the components necessary. The weight of the demonstration model without the wet battery is 15 pounds. However, further miniaturization could reduce the weight at least to half.

This meter is needed in connection with work on the problem of light amplification which has been carried on since 1952 in the Physics Research Branch, Wright Air Development Center. Here light levels between 10^{-8} and 1 ft-L. have to be determined. Figure 1 shows the schematic diagram for the complete lightmeter.

The photo multiplier tube, a 1P21, operates from 100 cycle AC current of approximately 1000 V. This current is produced by the 6V battery, and then passes through the vibrator VB7 and the transformer T_1. The capacitor C_1 shapes the wave form of the AC and prevents an unnecessarily sharp rise of the AC wave.

The measurement unit is a bridge arrangement which uses the double triode tube 12AV7. If no light falls on the photo multiplier tube, both sections of the 12AV7 will draw maximum current during the positive portion of the AC plate voltage on the 12AV7. If P_2 is properly balanced, the instruments I_1 and I_2 will then show no current. If light falls on the photo multiplier cathode, AC pulses will be produced on the plate of the photo multiplier as a function of the AC supply voltages and these are fed to section 1 of the 12AV7.

Figure 1a. Power Supply

These pulses have to be in coincidence with the positive pulses on the plate of the 12AV7. A timing network, consisting of C_2, C_3, and L, assures proper timing of the grid and plate pulses. It also determines, in connection with R_2, the correct load resistance for the photo multiplier plate circuit. C_4, C_5, and C_6 are responsible for the speed with which the meter responds. The switch S_5 permits changing this response time. The Relay RLS with the contacts S_3 shunts automatically the high sensitive instrument I_1 if the current in the bridge path exceeds 0.1 MA. This automatic switch arrangement is convenient if continuous readings are desired. If the value on I_2 drops to approximately two scale divisions, the switch opens and a full scale reading with a 30 times higher
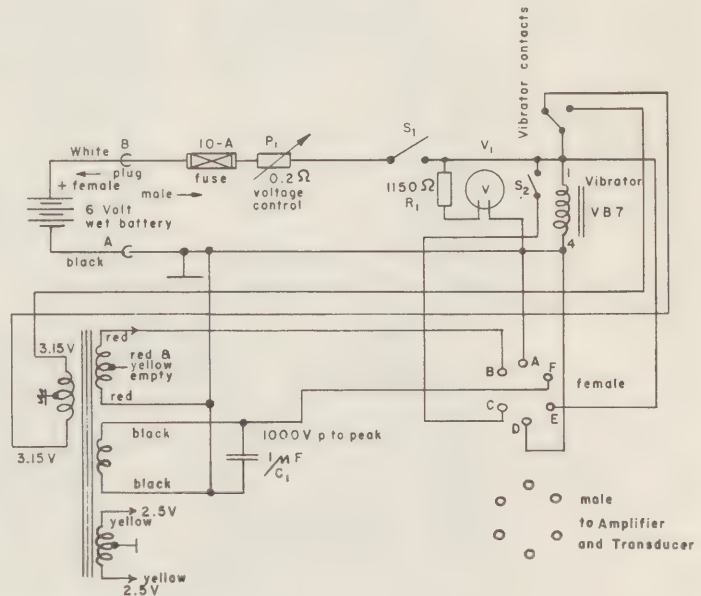
accuracy can be taken from I_1. Furthermore, it prevents automatically any damage through overloading on the instrument I_1.

The amount of AC voltage applied to the photo multiplier and its last dynode is controlled by the switch S_4 in connection with the resistors R_7 and R_8. The photo multiplier on low amplification will cover a light range from approximately 1 to 10^{-4} ft-L, and on high amplification it will cover from 10^{-3} to 10^{-8} ft-L.

Calibration of the Lightmeter

A calibrated precision foot-candle-meter which uses a light sensitive selenium cell was used as a standard. A nearly 100% diffuse reflecting screen was illuminated homogeneously with noon daylight. The illumination was measured with the foot-candle-meter, and the indication of the low level lightmeter was recorded with the lens directed toward the screen. During this measurement the well calibrated lens (Leitz 50 mm., 1.5 to 16) was closed to an aperture of 16. After this step, the light level with an aperture of 1.5 which would give the same reading on the meter was calculated with the well-known formula:

$$\frac{\text{Existing light level}}{\text{Desired light level}} = \left(\frac{\text{Existing aperture}}{\text{Necessary aperture}}\right)^2$$

Now the lightmeter was opened to an aperture of 1.5, and the illumination of the diffuse reflecting screen was reduced until the lightmeter showed the first reading again. In this manner a second calibrated source of luminance was obtained at a lower level. Next the aperture was closed step by step, and each meter reading was recorded. For each meter reading the equivalent luminance level for an aperture of 1.5 was calculated by means of the lens formula. Now the entire procedure was repeated. The lens was opened to 1.5, and the lighting on the screen was adjusted to give the same meter reading which had been obtained with the previous calibrated luminance level at a lens opening of 16. This yielded a third calibrated luminance level. The aperture was then closed again, step by step, and each meter reading was recorded. For each meter reading the equivalent luminance level for an aperture of 1.5 was calculated by the lens formula. This entire process was repeated four times, which gave enough calibration points to cover the entire light range from 1 to 10^{-8} ft-L. The instrument proved highly linear, so accurate calibration was possible without obtaining closely spaced calibration points.

The lightmeter was tested in the open country and the performance was found satisfactory. Many different objects were measured with a night sky illumination of 3.5×10^{-5} foot-candles. The lowest value was found for wooded areas, with an average of approximately 4×10^{-7} ft-L.
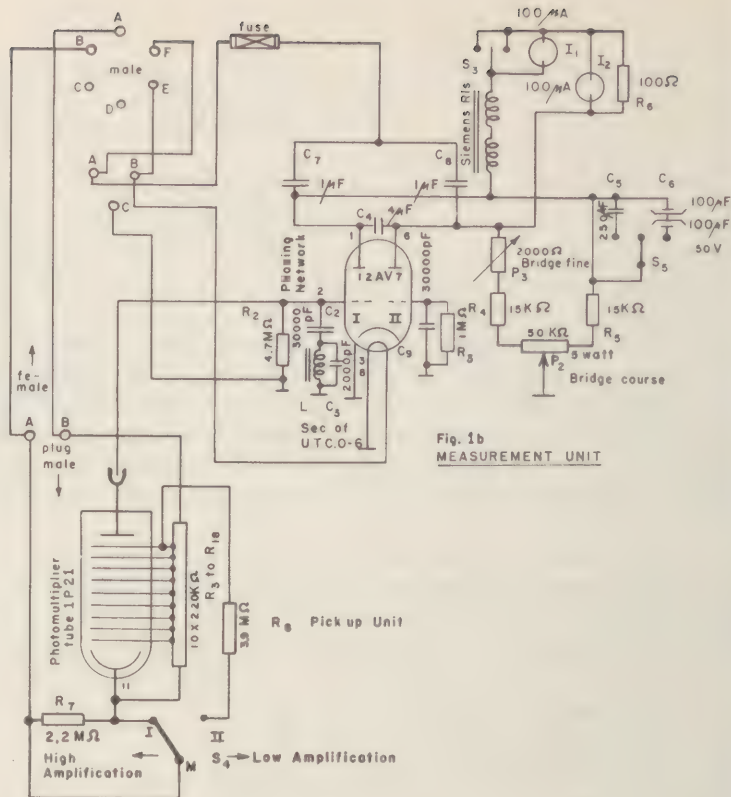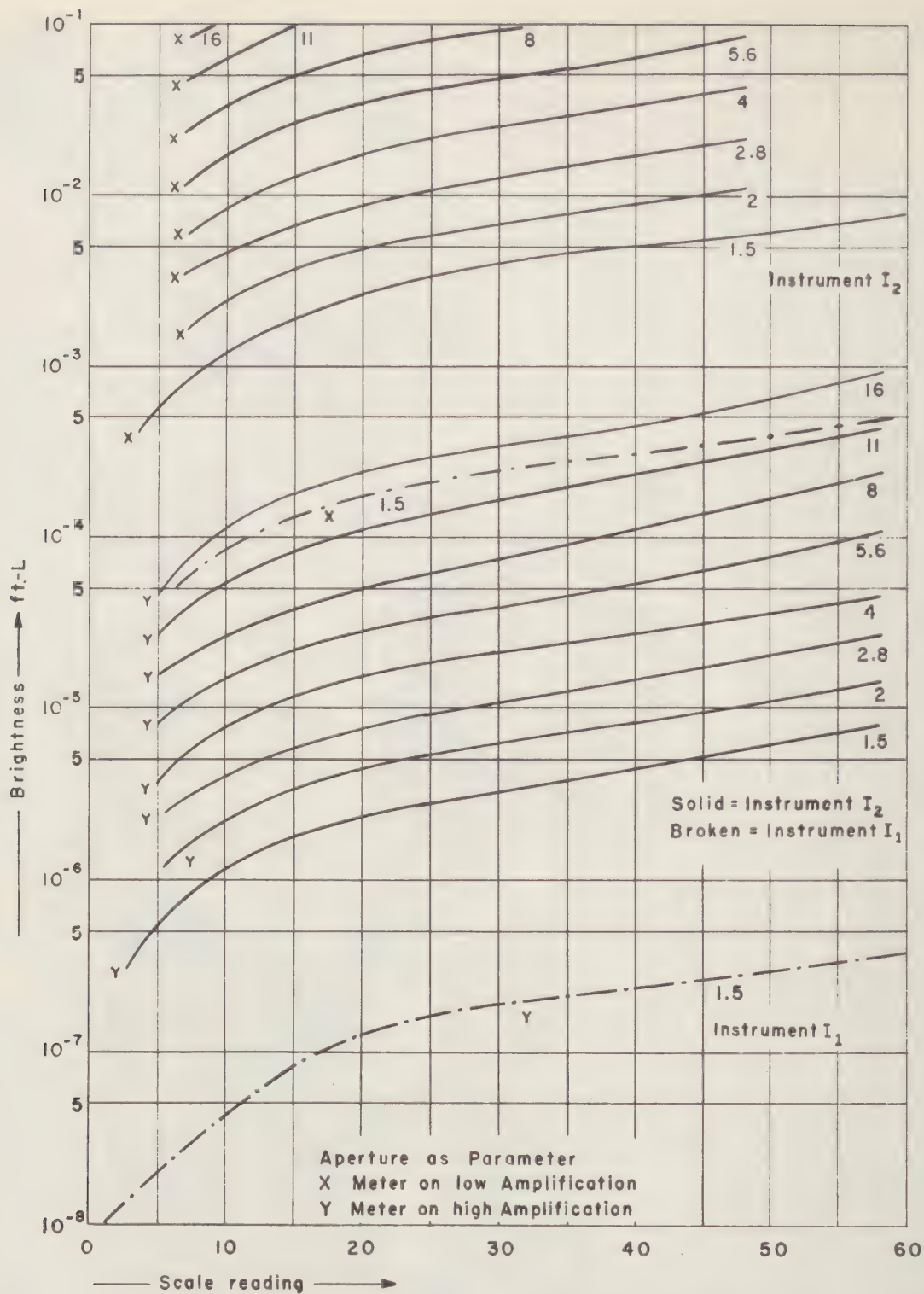
Figure 1b. Measurement Unit

CALIBRATION CHARACTERISTIC OF LOW LEVEL LIGHTMETER

Discussion

     Mr. Middleton protested vigorously about Mr. Gebel's use of photometric units in reference to physical radiometry performed at low luminances, pointing out that the only way to do photometry at low levels is with the human eye.

THE COLOR OF THE OVERCAST SKY

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The research here reported was initiated by a speculative remark made by the writer's colleague, Mr. C. L. Sanders, who wondered whether the light from the overcast sky might not be slightly greener in summer than in winter.

The general method is to consider a horizontally infinite layer of cloud of constant thickness h, lying above a flat earth of spectral reflectance r. The cloud has a volume scattering coefficient b. The spectral irradiance of sunlight on the top of the cloud has a downward component H_o. The Naperian absorption coefficient for the droplets is k_W, so that a fraction $k_W \cdot a = K$ of the light incident on a drop is absorbed by it (1).

Using a combination of the theoretical developments given by Mecke (2) and Dietzius (3), differential equations were set up for the downward flux H_1 and the upward flux H_2 at any distance x below the top of the cloud. By introducing appropriate boundary conditions, these can be solved without difficulty. The solutions will be given here for the special cases of the downward flux out of the cloud at the bottom ($H_{1,h}$) and the upward flux leaving the top of the cloud ($H_{2,o}$). They are

$$H_{1,h} = H_o \cdot \frac{2\rho}{e^{-\rho h}(\nu r - \mu + \rho) + e^{+\rho h}(\mu + \rho - \nu r)}$$

$$H_{2,0} = H_o \cdot \frac{e^{+\rho h}(\nu - \rho r - \mu r) + e^{-\rho h}(\mu r + \rho r - \nu)}{e^{-\rho h}(\nu r - \mu + \rho) + e^{+\rho h}(\mu + \rho - \nu r)}$$

in which

$$\mu = b[K + \beta(1 - K)]$$

$$\nu = b\beta(1 - K)$$

$$\rho = (\mu^2 - \nu^2)^{1/2}$$

$$\beta = 0.195.$$

If absorption of light by the water droplets can be neglected, we obtain the simpler equations

$$H_{1,h} = H_o \cdot \frac{1}{1 + \beta b(1 - r)h}$$

$$H_{2,h} = H_o \cdot \frac{r + \beta b(1 - r)h}{1 + \beta b(1 - r)h}$$

due to Dietzius (3).

It has in fact been found that absorption by the cloud water can be neglected even in highly polluted cloud, at least between the wave lengths 0.35μ and 0.70μ. The spectral absorbency of a number of samples of cloud water, collected through the kindness of

Mr. K. G. Pettit of the Flight Research Section, has been measured and calculations made with the above result.

On the other hand the reflectance of the ground, r, is of great importance. Figure 1 shows the spectral irradiance of the underside of a hypothetical cloud 2000 m in thickness, containing 2.5×10^8 droplets per cubic meter, each 10 microns in radius. This is shown for each of three ground conditions: new snow, green grass, and an average urban area. The sun is assumed to be 23° above the horizon.

The values of H_0 were obtained from published and unpublished data by numerous authors, due allowance being made for absorption by atmospheric ozone.
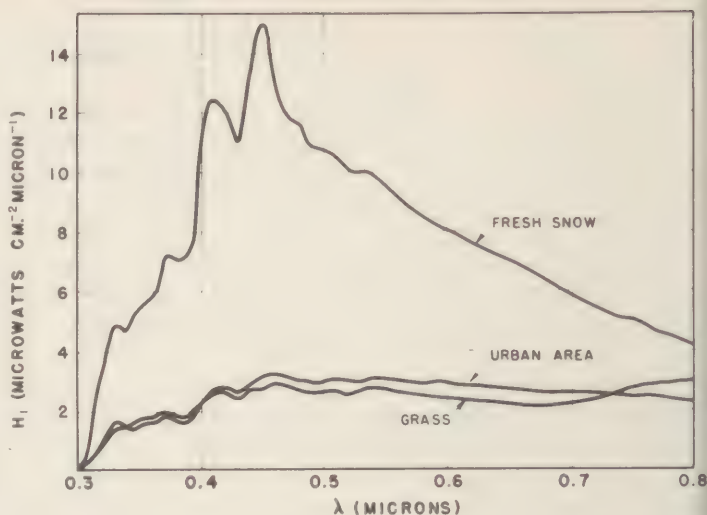

Figure 1

When the chromaticity and luminance are calculated from these data, it is found that the color of the underside of the cloud varies a good deal with the state of the ground. For example, over grass the correlated color temperature turns out to be $6100^\circ K$; over snow, $8150^\circ K$; and over an urban area, $5620^\circ K$. The color of the top of the cloud, however, is always nearly that of the incident sunlight.

A fuller account of this work is being submitted to the Journal of the Optical Society of America.

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A PRELIMINARY STUDY OF THE LIMITS OF VERTICAL
DISPARITY IN STEREOPSIS

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In an earlier paper (1) before this group I presented data which showed that there are limits of disparity within which stereoscopic depth perception could occur. Later data were described (2) which showed that for a patent or obligatory stereoscopic depth to occur there must be stimulation of horizontally associated disparate retinal elements in the two eyes. There was the suggestion in the experiments, however, that the horizontally associated disparate images could also be slightly disparate vertically and some stereoscopic depth could still be perceived.

The present report is concerned with the effect of vertical disparities upon stereoscopic acuity and with the determination of the limiting vertical disparity for which stereoscopic depth associated with a horizontal disparity could no longer be perceived. These data, while preliminary for this report, are still sufficient to permit us to make some conclusions.

The instrument previously used (1, 2) was modified in such a way that a vertical disparity could be introduced between the images in the two eyes of the test object. In order to make measurements with vertical disparities it is necessary to use a point light source as the test object. To introduce the vertical disparity in the instrument an afocal magnifying lens was interposed in the line of sight of one eye and the test light point. Such a lens when tilted causes a prismatic effect without introducing appreciable distortion or any chromatic aberration. The prismatic effect is approximately equal to the product of the per cent angular magnification of the lens and the angle of tilt.

With the eyes fixated upon a point light source, the test point light source was adjusted to a given position in the visual field. Using a constant stimulus method data were taken from which a psychometric frequency of stereoscopic-perception curve ("far" vs. "near") was obtained. From this the standard deviation was calculated using in part a modified probit analysis suggested by Finney. The stereoscopic acuity was computed, being proportional to the reciprocal of this standard deviation expressed in minutes of arc. A series of such curves was obtained for a succession of steps of increasing vertical disparities until stereopsis failed. The test point light stimulus was exposed for only 0.2 second.

The first series of data were obtained when the test light, adjusted 1/2 degree to the right of the fixation point, was judged "nearer" or "farther" than the fixation point itself. Then further series of data were obtained when a reference object (an illuminated needle) was set at a given distance before (or behind) the fixation point, symmetrically located (1/2 degree to the left of the fixation point) with respect to the test object. The test point light in this series was judged "nearer" or "farther" than this reference line, while the eyes were maintained on the same fixation spot.

Now in 1935 Loy (3) devised a stereoscopic testing device that used point light sources as fixation and test objects. He reported that when vertical disparities were introduced between the images of the test object, doubling and complete cessation of stereoscopic depth occurred. The quantitative results we have obtained with two observers are completely different, for it is found that large vertical disparities can be introduced, even when the two images are outside Panum's area of fusion and seen double, and still stereoscopic acuity

is high. This result, that for these two observers such large vertical disparities could be introduced, is surprising and even disturbing.

1. When the test point was $1/2^o$ above the fixation point and was judged "nearer" or "farther" with respect to the fixation point itself (or the apparent fronto-parallel plane), the stereoscopic acuity tended to be nearly constant as the vertical disparity between the images was increased, until at certain limiting disparities it suddenly became non-existent. With the 0.2 second exposure, these limiting disparities were of the order of 20 minutes of arc!

When the stereoscopic depth of the test light point was judged "nearer" or "farther" than a reference line (exposed simultaneously with the test light) below the fixation point but small distances in front of (or behind) the fixation plane, there was little effect on the range between limiting vertical disparities. For larger distances the range was markedly reduced.

2. When the point test light was placed $1/2^o$ to the right of the fixation point, there was a slow decrease in stereo-acuity as the vertical disparity was increased. Here again, however, the limiting vertical disparities were of the order of 20 to 25 minutes of arc.

When the test light was judged "nearer" or "farther" with respect to a reference object in front of (or behind) the fixation point frontal plane, symmetrical to the fixation point, the range of limiting vertical disparities were markedly reduced.

3. When the point test light was placed $3-1/2^o$ to the right of the fixation point, the stereo-acuity seemed more or less constant with change in vertical disparity, until the limiting vertical disparity was reached, when the stereo-acuity dropped suddenly. However, the range between the limiting disparities at $3-1/2^o$ is nearly half that obtained at $1/2^o$.

Further, the range between limiting vertical disparities decreases rapidly with increase in the horizontal disparities of the reference object, that is, for increased depth distances between reference line and fixation point.

These results are not what would be anticipated. Panum's areas near the fixation point are of the order of 6 to 10 minutes of arc vertically, and these areas increase rapidly toward the periphery. One would expect the range of vertical disparities within which stereoscopic vision exists would follow the same pattern. From the data just described they do not follow such a pattern.

This result has raised several problems of interpretation of the basis for stereoscopic depth perception.

Is it necessary to modify our concept that the limitations of stereopsis, and fusion, are confined to the degree of overlapping of the arborization of the optic tract fibers as they terminate in the occipital cortex, because these limitations of vertical disparity are so large?

No situation exists in the ordinary use of the eyes where vertical disparities of these magnitudes near the fixation point can occur. Only when a vertical fixation disparity exists because of a hyperphoria, could there be such a situation. The stereoscopic depth under these circumstances could not be a directly learned experience.

The data described were obtained for short exposures of the point light source. With longer exposure, large vertical disparities result in more obvious double images and the consequent fading of the stereoscopic depth.

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It is believed that more data should be available for study before the problem is discussed further.

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STEREOPROJECTION OF THE OCULAR FUNDUS

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To date, in the field of ophthalmology, stereophotography has never been a popular method of recording intraocular pathology. If one considers, however, the two most common ways in which retinal pathology manifests itself, namely, as: (1) a color change and (2) an elevation above or as a depression below the normal physiological plane of the retina, it will be immediately appreciated that a colored stereophotograph is the only complete and therefore accurate way of reproducing the ocular condition as it existed in life.

Such stereograms may be studied and appreciated by using a viewer or by projecting upon a screen. Small hand stereoviewers are a satisfactory way of demonstrating stereophotographs as are large table viewers, but each falls short of the full vividness of stereoscopic relief characteristic of a properly projected stereotransparency.

This preliminary report will serve to introduce, in general terms, a practical method by which retinal stereograms may be projected upon a screen for study and teaching purposes.

A retinal stereocamera still under investigation at the time of writing makes it possible to obtain very satisfactory colored stereophotographs of the retina. Details of the new development will be given in a later communication.

The 35 mm. retinal stereograms conform to the American Standard size thus permitting them to be viewed and projected with commercially available equipment. When projecting, one stereoprojector is used rather than two single or planar projectors. This feature immediately converts an extremely impractical method of stereoprojection to a most practical and controlled one.

The screen required in stereoprojection must be a smooth surfaced one rather than a glass bead surface. The latter, if used, will neutralize the polarized effect of the projected beam. Polaroid goggles are worn, which, in conjunction with the filters in the projector, produce the situation whereby two somewhat dissimilar views of the fundus are presented one to each side of the visual center of the brain. This parallax feature, or the slight difference between the two pictures of the stereoscopic pair, is the most important if not the sole requirement for an appreciation of stereoscopic relief or the so-called "third-dimension."

Stereoprojection differs in one main respect from planar or flat projection. In the former case the size of the audience which can appreciate the optimum stereo effect depends mainly upon the following three factors: (1) The size of the stereo screen, (2) The projecting distance, and (3) The focal length of the projecting lenses. At the present time the most practical combination of the three above factors is to use a fifty-inch screen; a projecting distance of twenty feet and four-inch focal length lenses in the stereoprojector. When two one-thousand watt lamps are used in the projector sufficient brilliance is obtained with polaroid projection from a twenty-foot distance. With this combination from thirty to fifty people may fully appreciate the stereoprojection.

In conclusion it may be stated that experience to date indicates that a practical comparatively inexpensive method of retinal stereography has been developed. The method proves to be a worthwhile addition to the armamentarium of intraocular ophtahlmic diagnosis and examination. It is anticipated that the new technique will be particularly valuable to the instructor in ophthalmoscopy as well as to a more accurate and complete way of recording opthalmic records.

THE AREA-INTENSITY RELATIONSHIP AT THRESHOLD FOR
THREE STIMULUS DURATIONS IN THE HUMAN FOVEA

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While it has long been known that an inverse relationship holds between the retinal size of a stimulus and its threshold intensity much disagreement exists on the exact quantitative relationship. Of the several general functions which have been proposed, that of Ricco[1] is most frequently cited. It states that the product of area and intensity are constant for threshold excitation in the fovea of the human eye. Such a statement implies (a) that all parts of the fovea are uniformly sensitive and (b) that threshold excitation involves a simple summation of the response of the units included within the stimulated area. Several experiments present evidence that Ricco's law holds over limited ranges of area. Lohle's[2] evidence indicates a departure from the exact relationship for circular areas whose diameters exceed 10' of visual angle. The data of Graham, Brown and Mote[3] show a departure from Ricco's law above about 6' diameters in the fovea. The more recent data of Blackwell,[4] using contrast thresholds, show departures above 10' diameters.

Wald[5] and Graham et al. have proposed general theoretical accounts which are based upon more complex views of summation at threshold and which are intended to predict size-intensity relationships for both fovea and periphery. Wald assumes (a) spatially independent receptor elements in the retina (no spatial interactions), (b) homogeneity of sensitivity over the region described and (c) a constant number of excited elements at absolute threshold. This leads him to the expression:

$$(A - n_t)^K I = \text{Constant} \tag{1}$$

where A is the retinal area, n_t some constant number of elements responding at threshold and I is the threshold light intensity. This is a more general expression of the same form as Ricco's law. Where n_t is very small and K equals unity, it approaches Ricco's law. Both are simple power functions and appear as straight lines when retinal area and intensity at threshold are plotted on logarithmic coordinates. They differ only in the slope of the line.

Graham, Brown and Mote present an entirely different theoretical formulation which includes a consideration of spatial interactions in the retina. Based upon certain perceptual observations of Abney and experiments of Adrian and Matthews and Hartline, they hypothesize that the threshold is determined by the response of central elements within a stimulated area. More peripheral elements within that area summate with the central elements to contribute to the total excitation in inverse proportion to their distance from the center. Upon assuming a constant intensity effect within each elemental area, assuming the contribution to the total excitatory effect of each elemental area to be inversely proportional to some power of the radius, they integrate the excitatory contributions over a circular area and arrive at:

$$\log I/I_0 = CR^{P-2} \tag{2}$$

I_0 is the threshold value of the contributing central elements, assumed to be constant, I is the intensity at threshold and R is the radius of a circular stimulus area on the retina; C and P are constants. When plotted on logarithmic coordinates this equation—as contrasted with the Ricco and Wald expressions—shows a curvilinear function with the approach

to an asymptote at large values of area, signifying the decreasing contribution of elements more distant from center. Graham, Brown and Mote show data which approximately agree with their theory for areas ranging in diameter from 1' to 1° in the fovea and above 20' in the periphery. It should be noted that the data of Abney and Watson[6] and of Pieron[7] which were fitted by Wald to his expression over wide ranges of area in the fovea cannot be described by the Graham et al. function. Nor can the latter's data be fitted by the Wald or Ricco expression.

The essential difference between the Ricco and Wald expressions on the one hand and that of Graham et al. on the other is that the former assumed no interactions between stimulated elements while the latter assumes a form of spatial summation. There exists, however, little evidence for spatial interactions in foveal vision. In fact, several lines of evidence point towards isolated functioning in the fovea with the single cone as the functional unit. The histological evidence presented by Polyak seems to favor the conclusion that there is little possibility of spatial interaction in the central fovea. The central fovea over the flat floor of the foveal pit, a circular region of diameter about 1°20' of visual angle contains closely packed cones which synapse with midget bipolar cells. According to Polyak,[8] "there is on the one hand no reciprocal overlapping but a complete separation from one another of most of the adjoining 'bouquets' or, in other words, of the midget bipolars, and in this way of the cones. This is certainly so in the central area--." Polyak also reports the absence of horizontal cells in the central fovea. He concludes, "The inference which may be drawn from this anatomical arrangement is that the 'pure cone system' is made up exclusively of the monosynoptic structural-functional units and all arranged parallel... This implies the ability of each unit to function independently."

Psychophysical experiments have shown that foveal acuity corresponds to the diameter of the foveal cones. Helmholtz pointed this out. Recently, O'Brien utilized interference patterns on the fovea in order to avoid the aberrations usually produced in image formation. He found, for a variety of wavelengths of monochromatic light, that resolution is possible where a single line of cones separates the stimulated areas. This finding would best be explained in terms of a high degree of functional isolation of elements in the fovea.

The evidence from psychophysical data on the resolution of targets and the histological findings in the fovea present strong arguments against spatial interactions in central foveal vision. From that evidence one would predict that the area-intensity function, for that region, would closely approximate a simple power function, with no loss of excitation for increased area.

In light of the above, it was thought justified to gather new data on the area-intensity function in the fovea, attempting to control variables which might have led to a loss of summation in previous experiments. Two such factors are thought to be (a) inadequate fixation of the eye, (b) uncontrolled stimulus duration.

With inadequate fixation it might be expected that on the one hand wandering movements of the eye might include rods within the stimulated region or that, for long durations, a loss of temporal summation would occur because of eye movements. Graham, Brown and Mote took particular care with fixation having noted the inadequacy of most of the previous studies in this regard. In the present study a new type of fixation has been employed which is believed to afford a still higher degree of fixation control for foveal threshold measurement.

Previous studies have employed long and usually uncontrolled stimulus durations. Ricco used an adjustment technique which took an indefinitely long exposure to obtain a threshold, as did Piper[9] and Graham, Brown and Mote. Abney and Watson used stimulus durations of "about" 1 sec.'s duration as did Wald. It seems likely that, with long durations, adaptive effects might differentially alter the absolute threshold for different stimulus areas. It

might also be expected that the effect of eye movements upon the threshold would be great-
er with long stimulus durations. Graham and Margaria[10] and Karn[11] have shown that, for
long durations, increased total energy is required to reach absolute threshold as retinal
size is increased. For short durations, according to those studies, total energy remains
approximately constant with increased area. In the present study, it was possible to meas-
ure the area-intensity relationship for fixed, short stimulus durations.

Apparatus

The apparatus is illustrated in Figure 1. It consisted of a light source, the Sylvania
R1131C Glow Modulator Tube, the beam of which passed through a set of neutral density
filters for intensity control, and evenly illuminated a flashed opal plate. The front surface
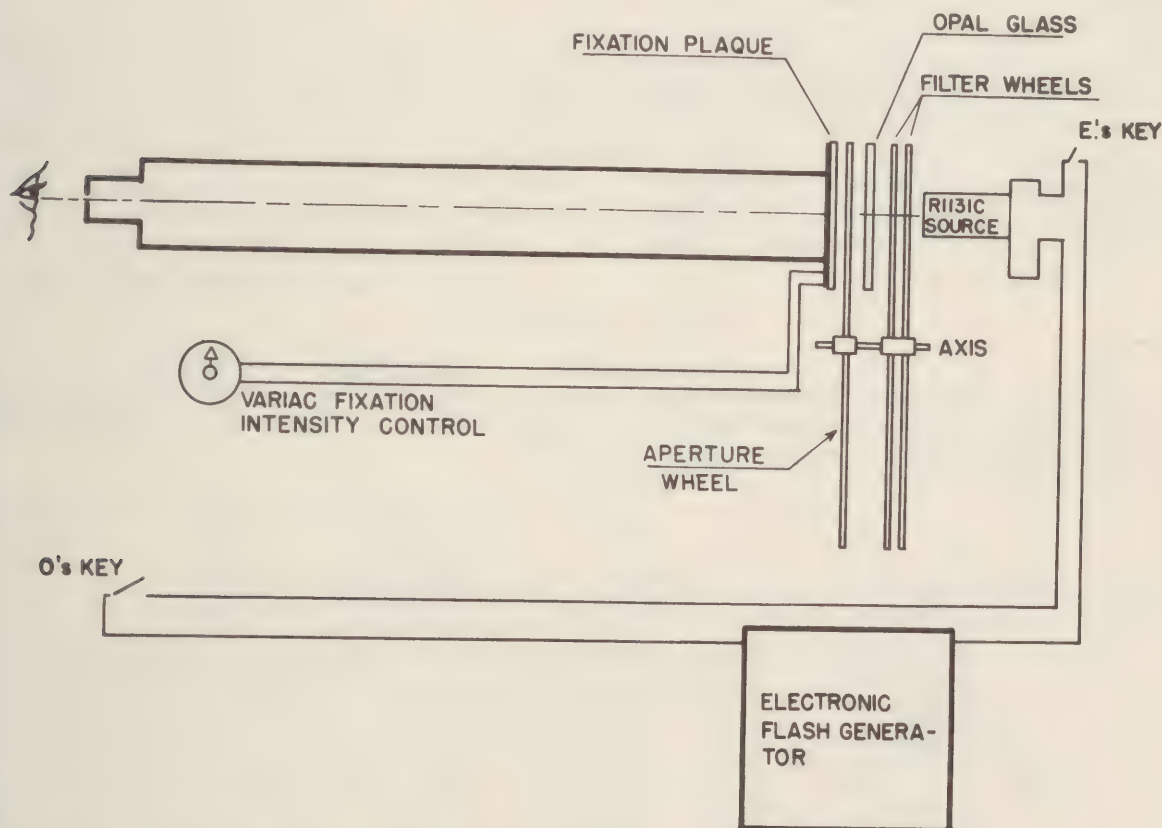

Figure 1. Schematic sketch of the apparatus used to obtain absolute thresholds for various
stimulus sizes at controlled durations.

of the plate was viewed by the observer through a light-tight tube. Stimulus size was
varied by placing different sized circular apertures against the plate. The flash tube was
powered by an electronic flash generator. By means of this device, rectangular impulses
of continuously adjustable duration and amperage were supplied to the tube. For calibrat-
ing the duration of impulses, the impulse was fed to an oscilloscope and superimposed on
a sine wave of known frequency. The intensity of the source was maintained constant by
adjusting the glow tube amperage to yield a constant current output from a phototube, at a
fixed distance. The light from the glow modulator tube appeared white. A visual match
was obtained with it to an incandescent lamp emitting light of 3900° K color temperature.
The intensity of the stimulus could be varied in 0.1 log intensity steps over a 6 log unit
range by means of written neutral density filters which had been calibrated using the same
source as used in the experiment.

The fixation of the eye was aided by a pattern of four short luminous lines arranged to form the vertical and horizontal arms of a cross, with a 2° gap in the center. The pattern is illustrated in Figure 2. The center of the gap in the cross coincided with the center of the circular stimuli and the fixation pattern was the same distance from the eye as the stimulus, so that accommodation of the eye remained constant. The four arms of the cross were of a uniform luminance and color, a yellowish white. The intensity of the fixation pattern could be adjusted by the observer in very small steps.

Seven circular stimuli were chosen, ranging in visual subtense from the region of 1' in diameter to 1° in diameter. The exact sizes are shown in Table I.

Procedure.

The observer was dark adapted for 15 minutes, then the fixation pattern was turned on and he was instructed to "adjust
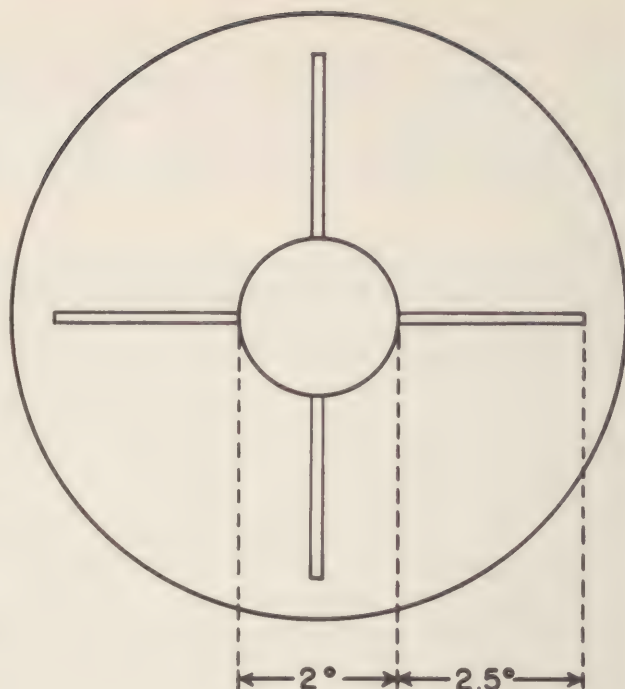
FIXATION PATTERN

Figure 2. Fixation pattern showing angular sizes.

Table I

MEAN LOG THRESHOLD VALUES* FOR TWO OBSERVERS FOR EACH OF
THREE STIMULUS DURATIONS FOR SEVEN STIMULUS SIZES IN THE FOVEA

Radius of Stimulus (mm.)	Radius Minutes Vis. Angle	Observer GBL			Observer HGS		
		.001	0.04	0.25	0.001	0.04	0.25
			seconds			seconds	
.191	.578	-----	-1.61	-2.52	-----	-1.13	- .82
.818	2.477	-1.41	-3.00	-3.73	- .84	-2.51	-3.08
1.328	4.022	-1.92	-3.24	-4.20	-1.19	-2.67	-3.56
2.500	7.572	-2.53	-4.00	-4.55	-1.64		-3.88
4.805	14.553	-3.04	-4.43	-5.02	-2.39	-3.93	-4.52
7.239	21.924	-3.30	-4.75	-5.50	-2.68	-4.30	-4.82
9.500	29.036	-3.57	-4.99	-5.97	-2.95	-4.68	-5.05

*Threshold is in relative intensity units. O. log relative intensity corresponds to approximately 13.5 ft. L.

the brightness control until the pattern is the dimmest that you can clearly see while fixating the imaginary center of the cross. Now look directly at one arm of the cross." Usually that arm would disappear when fixated centrally, since it fell in the less sensitive fovea. If not, the observer was instructed to "reduce the intensity further until the arms disappear when viewed directly and reappear when the center of the cross is fixated." This procedure is thought to have minimized the possibility of the fixation lights having summated with the stimuli in the fovea. He was instructed: "When I say 'now' fixate the center of the cross and when you are sure of fixation, close the key near your right hand. If you see the flash of light, signal 'yes,' if not, 'no.'" O. was prevented from obtaining more than one flash per trial. O. was instructed to report any trial where one limb of the cross had

disappeared, indicating loss of fixation. Those trials were repeated. This procedure per-
mitted a check on fixation and is thought to have insured foveal stimulation throughout the
experiment with minimal hunting movements of the eye.

Six threshold determinations were made per stimulus area, per sitting, by the serial
method of limits using 0.1 log intensity steps. Data are here reported on five or more
sittings for each of the seven stimulus areas, constituting the average of 30 or more single
threshold determinations per area for each of three stimulus durations with two observers.
The durations were .001, .04 and .25 secs. Right eye monocular observation was used
throughout.

Results

Table I shows the average threshold values for each condition. Figure 3 shows the
average threshold values on a log radius vs. log relative intensity scale. There it may be
seen that for all three durations and for both subjects the values closely fit a straight line.
This is evidence that the relationship between area and threshold intensity for almost the
entire central fovea is a simple power function. A statistical test of the goodness of fit to
a straight line was made with the E^2/r test. It was found that in no case did the data
deviate significantly from a straight line fit. The data have been fitted with straight lines
by the method of least squares. Radius rather than area was used.
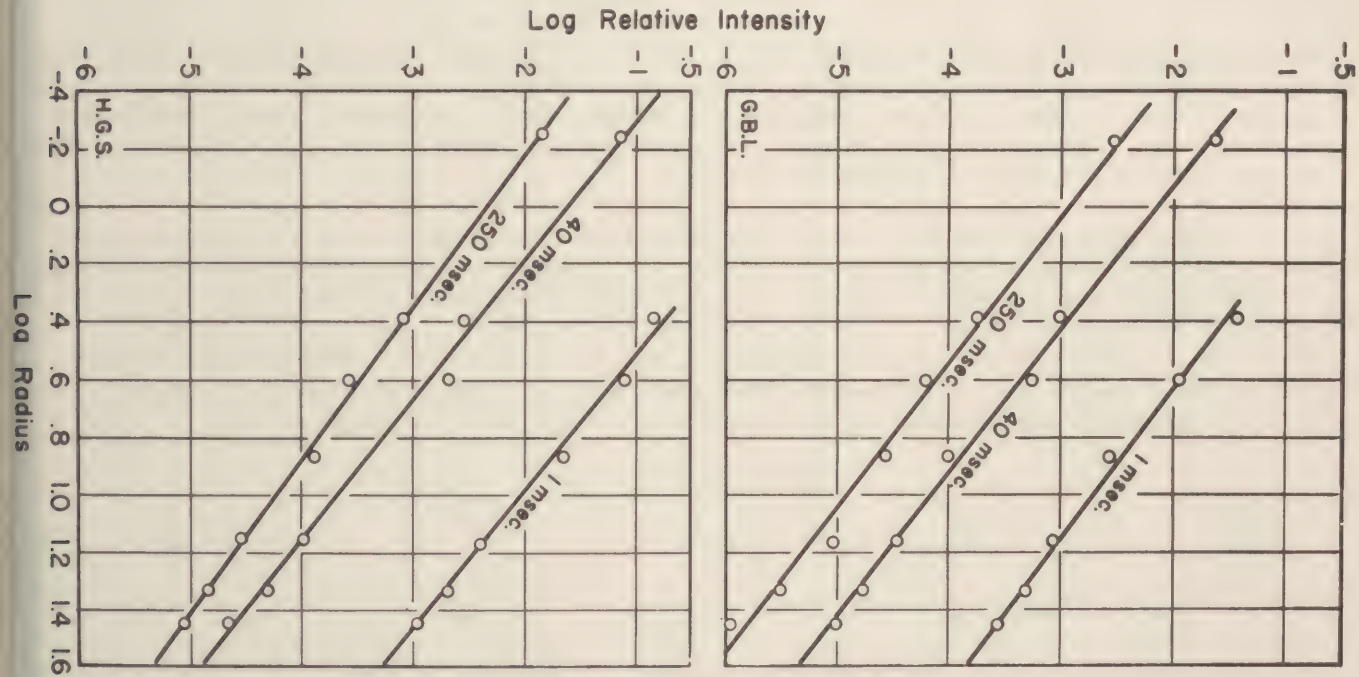
Figure 3. Mean absolute thresholds as a function of stimulus radius for three stimulus dura-
tions on two observers.

A slope of K = -2 would confirm Ricco's law. It will be seen in Table II, where
the least squares solutions for K are tabulated, that the values fall near -2, ranging from
-1.88 to -2.01. The average slope value, over all durations for both subjects, is -1.96.
No consistent trend of the values of K seems to develop with change of duration over the
durations employed.

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Table II

LEAST SQUARES VALUES OF THE
SLOPE VALUE K FOR TWO OBSERVERS
FOR THREE STIMULUS DURATIONS

Duration	GBL	HGS
0.001 second	-1.89	-2.01
0.040 "	-1.98	-1.99
0.250 "	-2.00	-1.88

Conclusions

In the foregoing analysis, it was predicted that the foveal area-intensity relationship should take the form of a simple power function--showing no influence of spatial interactions. The data obtained have supported this contention for the conditions of measurement used.

The values which were obtained for K approach -2 very closely. Thus, for the conditions employed and over the range of durations studied, it appears likely that the Ricco formulation of simple summation in an entirely homogeneous region cannot be rejected, although the more general Wald expression will also account for the data. It is clear that with the constants which are indicated by our data the operation of a constant threshold number of elements, n_t as proposed by Wald, can neither be accepted nor rejected since, if present, their number must be insignificantly small relative to those included within the stimulated area. It appears that Ricco's law comes close to describing the data obtained here over almost the entire rod-free fovea.

It should be noted that the tendency towards somewhat larger slope values than the -2 predicted by Ricco's law can be predicted from the gradually reduced density of cones, from the center of the fovea to 30' from the center. O'Brien and Miller[12] have very recently published a quantitative statement of this gradient. It shows the separation of adjacent cones to be a simple power function of the distance from the foveal center in minutes of visual angle. Integrating our stimulus areas over this function, there results a power function of the form obtained experimentally, with a slope value in the neighborhood of -1.9.

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EFFECTS OF EARLY DEPRIVATION OF LIGHT OR PATTERN VISION IN CHIMPANZEES, WITH SPECIAL REFERENCE TO BINOCULAR MOTOR ANOMALIES

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This study began more than a decade ago in an effort to determine the significance for primate visual development of function and learning as contrasted with innate growth factors. Chow, Knauer, Lashley, Nissen, Semmes (1, 2) and others at the Yerkes Laboratories of Primate Biology have contributed much to this long-term exploratory effort. None of us was quite prepared for the drastic effects which visual restriction had on our first infant chimpanzee subjects. We had to improvise tests adapted to the subjects' capabilities while we were still in the process of discovering these capabilities. Most tests which we planned to use in advance were so far beyond the visual capacity of the animal that they served only to show the gross nature of the arrest in development. Thus, a brachiation ladder that was to measure depth perception at close range revealed only that the animal failed even to orient directionally. Likewise, no data were obtained on innate color preferences because there was no fixation or orienting behavior to areas of different hues. Fixation and refixation of a single light source in a dark surround was the clearest initial visual act that we could get. Optokinetic responses were clear where a spontaneous nystagmus did not seriously interfere. So this was the level at which our initial tests had to be pitched.

DEPRIVATION SCHEDULES

After two subjects had been carried along into the 3rd year, and after one of these showed severe optic nerve atrophy, it became apparent that we had at least three types of visual restriction to investigate and two or more classes of behavioral response variables to measure. By now we have made comparisons of the effect of three types of restriction: (1) total light deprivation, (2) patterned light deprivation, and (3) restriction of gross bodily movement during early pattern vision. These different environmental restrictions have been maintained for a comparable period of 7 months from birth in four subjects. A 5th subject served as a "normal" control for this 7-month deprivation group. One animal was given only unpatterned light between 10 and 18 months of age.

Light deprivation has been complete in three other animals: (1) from birth to 3 months, (2) from birth to 7 months, and (3) between the ages of 8 months and 24 months. Two subjects, the first pair studied intensively, were restricted to 5 minutes of light per day from birth to 16 months, when they began to receive about 20 minutes per day until one was 21 and the other was 33 months of age.

TECHNIQUES OF DEPRIVATION

Total deprivation of light was achieved by keeping the animals in a darkroom. All routine feeding and care was accomplished in darkness. Animals were brought out (usually once a week) with hoods on for special checkups and weighing.

For patterned light deprivation a white translucent Plexiglas hemispheric dome was used which transmitted diffuse light of all visible wavelengths. Our standard periods of exposure provided for 90 minutes of light daily. The animals were held supine with arms encased in loose cardboard cylinders and with a canvas band across the chest and abdomen.

This same holder was used for the third condition: restriction of bodily activity during early pattern vision. For this condition the animal could look at ceiling, walls, a light globe, and at moving persons in the room. Visual-tactual associations were prevented.

OPHTHALMOSCOPIC EXAMINATIONS AND HISTOLOGY

Dr. W. J. Knauer, M.D., Ophthalmologist of Jacksonville, Florida, conducted repeated ophthalmoscopic examinations of our subjects. These showed that in the 3 animals having complete or near-complete light deprivation for 16 months there was pallor of the nerve head and a shriveling of the blood vessels, which varied considerably from animal to animal. These manifestations of atrophy were slight or entirely absent in the other subjects.

To the present time only one retina has been examined histologically. This was on animal No. 142, whose eye was removed immediately after death at 2 years, 9 months of age. This subject had received diffuse light, only, for 90 minutes daily from birth to 7 months of age. The histological picture was entirely normal.

A 6 per second occipital EEG was obtained on a 7-month old infant (No. 136) upon first removal from the darkroom. A slightly faster infant "alpha" rhythm was recorded from an older subject whose scope of visual behavior was still severely limited.

TESTS OF VISION

As many "naturalistic" observations as possible were made on all subjects. These were supplemented by tests and training procedures to give evidence of visual discrimination and visual learning ability. The procedures numbered 1 through 14 were repeated daily until presence of the responses were noted, or until a stable form of reaction was present.

1., 2., and 3. Pupillary, lid closure and grimacing in bright light, and startle responses were measured first with a flashlight, and where the responses were not obtained a 200-watt bulb with reflector was used.

4. Visual fixation and pursuit of a moving light was determined by moving a flashlight, both with and without a reflector, in horizontal and vertical planes. In general the lighted bulb without reflector gave better results. First "pursuit" was invariably a series of re-fixations with quick movements of small amplitude. Tests were made in the darkroom and in a moderately lighted room.

5. Heterotropia was observed in all tests for which there was sufficient illumination of the subject's pupils to make them clearly visible. Small degrees of heterotropia were most easily seen when fixation or pursuit of the lighted flashlight bulb was under observation, since the reflection of this spot of light in or near each pupil provided a fairly accurate measure of the orientation of each eye.

6. Spontaneous nystagmus was noted under the same conditions as for heterotropia. A monocular cover test was also used to determine the presence of nystagmus. Our criterion for "spontaneous nystagmus" required that with no movement in the visual field there was episodic to and fro movements of the eyes, movement being more rapid in one direction (the direction of the nystagmus), with three or more cycles of movements occurring in quick succession.

7. Optokinetic nystagmus was observed while the subject was held in the attendant's lap at the center of a rotating drum which bore alternating broad stripes of white and black.

8. Eye blink to movement in the visual field was tested under two conditions: (a) The experimenter passed his flat hand across the field of vision at a distance of 14 inches from the subject's face. (This consistently produces a blink and often a gross startle response in a normally raised chimpanzee of 3 to 4 months in age.) (b) The experimenter moved the edge of his hand toward the subject's face.

9. Cessation of startle to touch of the face was tested as a sign of awareness of an approaching hand. The hand was moved slowly toward the face to give ample time for regard, and a light touch of the face was given. Results were ambiguous for some animals, but others consistently startled for a number of weeks following removal from the visual restriction, and then showed a definite time of disappearance of this response.

10. Visual pursuit was credited when the eyes followed a slowly moving person or test-object, and was determined when the animal lay in his own crib, sat on an attendant's lap, or sat in a chair-table unit. If clear following movements or a series of successive refixations occurred in any of these situations, the item was considered "passed."

11. Fixation responses were measured under the same conditions as pursuit, and required continuous regard for 3 seconds or longer.

12. Mouth and hand approaches to the feeding bottle were usually observed at feeding time. Some infants also sought contact with a person's hand at almost any opportunity. Visual recognition and approach to the hand were recorded.

13. Discrimination of the feeding bottle from other objects came much later than its initial recognition as judged by approaches with the mouth. Once approach began, it occurred to a wide variety of other objects which were used for testing discrimination. When the bottle could be discriminated from the experimenter's hand, a white square card, a grey cardboard cylinder, and a yellow pencil, this discrimination test was credited.

14. Convergence to an approaching stimulus was observed both with a lighted flashlight bulb and with a bright yellow pencil. Sometimes one, sometimes the other was found to produce greater degrees of convergence as it was brought slowly toward the subject's face. Infants raised in normally lighted surroundings by six months of age maintain binocular fixation under these conditions until the test object is within 3 inches or until it is touching the animal's protruding upper lip.

15. Fear of the visually unfamiliar person or object appears spontaneously at a certain stage of development in the chimpanzee. This can be seen most clearly when the animal is at ease in familiar surroundings and the test person or object is introduced as one item in a series with, or simultaneously with familiar persons or objects. Care was taken in the tests to avoid cues from other modalities, the auditory and tactual proving to be particularly important. These tests were given approximately twice a week.

16. The conditioned avoidance of a "shock-disc" was established as a means for determining rate of visual learning. A plywood panel, 38 cm. in diameter, painted with 2-inch vertical yellow and black stripes, and bearing a small electrode at its lower margin was shown the infant from a distance of 40 cm. for 5 seconds. Then it was advanced slowly until a mild electric shock was delivered on the subject's chin. The criterion of learning used in the accompanying table was the number of shocks necessary before the second clear anticipatory avoidance occurred. Training trials were given once during morning feeding and once during afternoon feeding each day until stable response appeared.

17. Visual form, size, and color discriminations were then developed. Each feeding was interrupted 6 times. If the original plaque was shown, it was followed by shock. If any one of a series of new plaques were shown, these were followed by food from the

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feeding bottle. These new plaques differed from the original either (1) by having horizontal rather than vertical stripes, (2) by red stripes replacing the yellow, (3) by having an over-all diameter of half that of the original, and (4) by a square rather than circular outline, but with total area equivalent. Numbers of trials required to develop approach responses to the new plaques were recorded, the continuing avoidance of the initial plaque being concurrently required.

18. Acuity was determined by giving discrimination training with only the vertical vs. horizontal stripes. Without permitting the breakdown of the discrimination habits, the experimenter gradually introduced new plaques with narrower and narrower stripes until discrimination failed or until stripes of 1/3 mm. were discriminated at the distance of 40 cm.

RESULTS

Time does not permit the full description of results on all 10 subjects. Effects of total light deprivation will only be summarized by the statement that a 7-months period of deprivation does not seem to produce irreversible atrophic changes, but apparently periods of 16 months or more do. These latter are indicated in Table 3, animals 6, 7, and 10.

The comparisons between four different kinds of visual restriction, maintained from birth to 7 months (or in the case of one subject kept in darkness, from birth to 3 months), are shown in Tables 1 and 2. For purposes of the present discussion primary interest lies in the fixation and pursuit movements, the nystagmus, the heterotropias, and the convergences. It will be seen that there are rather large differences between the "free moving" animal and the others. In many respects this animal responds as does any chimpanzee of 7 months who has had full vision all day long, rather than only 90 minutes per day.

The ambiguity of observations of optokinetic nystagmus with animals 125, 142, and 136 is exemplified by the following protocol, entered when one of the "diffuse light" subjects had lived 13 days in normal surroundings: "Subject well relaxed, conditions seemed optimal but results were still not clear. There is so much spontaneous (eye) movement and spontaneous episodes of nystagmus, about three-fourths with jerking phase to left, that the occasional brief periods when movements correspond to the drum rotation could be accidental." The heterotropia seen at 7 months in four subjects was primarily divergent with small vertical components. Animal No. 140, on the other hand, had a convergent squint that was highly variable. Within 6 weeks this had been markedly reduced and on some days was not seen at all. At approximately one year after removal from darkness an alternation of fixation was noted, and a slight exotropia accompanied this. Since that time all observations have indicated good binocular coordinations.

Follow-up observations on our 10 chimpanzee subjects reveal that 7 of them have residual squint and nystagmus. Three cases could be ascribed to what seems to be irreversible atrophy of retina and/or nerve. Table 3 summarizes the present status of all subjects. The 3 subjects with normal binocular motor coordinations have had either (1) a daily minimum of 90 minutes of normal pattern vision from birth, (2) an early period of normal vision to 10 months of age followed by 8 months with vision restricted to diffuse light, or (3) complete deprivation of light for not more than 3 months after birth. Since both subjects that were given unpatterned light from birth to 7 months show residual squint and nystagmus, the critical period for the development of optimum oculomotor fixation and eye movement coordinating responses seems to lie between the ages of 3 and 7 months. Anomalous eye movement patterns that develop within this age period prove resistant to later extinction. Adequate responses that do appear when a patterned visual environment is provided beginning at 7 months must compete with a residual nystagmus and squint. These residual anomalous eye movements gain control over the final common path under stimulation that requires prolonged maximum binocular convergence, or when one eye is occluded, as in the cover test.

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Table 1

THE EFFECTS OF DIFFERENT CONDITIONS OF VISUAL DEPRIVATION
UPON VISUAL RESPONSES WHEN FULL VISION WAS FIRST MADE
POSSIBLE AT AGE 7 MONTHS, OR 3 MONTHS

CONDITIONS	FREE MOVING	HOLDER ONLY	DIFFUSE LIGHT	DIFFUSE LIGHT	NO LIGHT	NO LIGHT
Minutes of light per day	90	90	90	90	0	0
Age at First Tests	7 months					3 months
Animal No.	119	148	125	142	136	140
Pupillary reflex	+	+	+	+	+	+
Startle to sudden light	+	+	+	+	-	-
Optokinetic nystagmus	+	+	?	?	?	+
"Spontaneous" nystagmus	-	-	+	+	+	-
Cover nystagmus	-	+	+	+	+	
Heterotropia	-	+	+	+	+	+
"Pursuit" of light in dark	+	+	2	+		1
in light	+	+	3	2	2	
Pursuit of object	+	+	11	13	13	15
Fixation of person	+	+	17	13	30	23
Blink to movement a. lateral	+	13	9	6	15	12
b. toward	+	14	9	6	56	16
c. differentiated	9	47	145	>400	110	68

(1) A plus (+) sign signifies immediate presence of the response.
(2) A minus (-) sign means that the response was consistently absent.
(3) Numbers refer to the number of days after full vision was permitted until the response occurred.
(4) The question mark (?) means that results were ambiguous.
(5) Lack of entry indicates that the crucial observation was not made.

Table 2

THE NUMBERS OF DAYS AFTER FULL VISION WAS PERMITTED BEFORE CERTAIN RECOGNITION RESPONSES WERE GIVEN

CONDITIONS	FREE MOVING	HOLDER ONLY	DIFFUSE LIGHT	DIFFUSE LIGHT	NO LIGHT	NO LIGHT
Minutes of light per day	90	90	90	90	0	0
Age at First Tests	7 months					3 months
Mouth approach to bottle	+	11	19	20	27	23
Fear of strange object		56	35	38	33	
Fear of unfamiliar person		63	157	?	169	143
Trials for learning to avoid noxious stimulus	9	18		15	20	18
First convergence	+	8	40	59	58	41
to 5 inches	+	40	74	59	76	
to 3 inches	+	82-225	124	107	93	<390
to lip contact	9	>640	131	385-655	117	<390

Below the dashed line are given the numbers of days required for increasing ability to give binocular convergence to a near point. "Trials for learning" in item four were given at the rate of 2 trials daily.

At 2 years and 7 months of age animal No. 125 showed binocular fixation under most everyday conditions. Convergence to the nearpoint was usually successful, but not easily maintained. Continued regard of a near object resulted in divergent movement of one or the other eye. Then a jerky "spontaneous nystagmus" occurred episodically. By contrast the animal with diffuse light for 8 months between 10 and 18 months of age showed motor incoordinations for only the first 10 days after return to normal visual conditions. There was for 3 days a prominent oscillatory tremor, horizontal, at a rate of approximately 8 cycles/sec. About half the time there was a visible jerking of the head synchronized with the eye movements. This was slightly in evidence in episodes on the 7th day and gone on the 8th day. Exotropia with also a small left eye elevation disappeared by the 8th day. Convergence to near improved rapidly to normal in 10 days. This can probably be regarded as a recovery of the well developed earlier (prior to 10 months) oculomotor coordinations.

Table 3

PERSISTING VISUAL ANOMALIES IN CHIMPANZEES WITH DIFFERENT TYPES OF EARLY VISUAL RESTRICTIONS

	APPARENT IRREVERSIBLE ATROPHY	PERSISTING RESIDUAL NYSTAGMUS	PERSISTING RESIDUAL SQUINT	PRESENT AGE [1]
Patterned light, movement				
7 months	no	no	no	3 yr., 5 m.
Patterned light, no movement				
7 months	no	cover nystagmus	yes	2 yr., 4 m.
Diffuse light				
7 months	no	yes	yes	2 yr., 7 m.
7 months	no	yes	yes	2 yr., 9 m. [2]
10-18 months	no	no	no	3 yr., 6 m.
5 minutes daily light				
16 months + 21	yes	yes	yes	7 yr., 6 m.
16 months + 33	yes	yes	yes	7 yr., 7 m.
Total darkness				
3 months	no	no	no	4 yr.
7 months	no	yes	yes	4 yr., 10 m.
8-24 months	yes	yes	yes	5 yr., 11 m.

[1] Age as of last complete survey, September, 1952.
[2] Age at death, November, 1951.

SUMMARY AND CONCLUSIONS

At 3 months, 7 months or 16 months, a first, immediate, and innate oculomotor be-havior is an eye movement which tends to bring a single light source into central fixation. Subsequent response to pattern gains sensitivity to more subtle (less high contrast) stimula-tion as a function of the nature and extent of exposure to such stimulation. This improved discrimination can be conceptualized as a conditioning and learning process. This process depends on the repeated reinforcement derived from such consummatory events as (1) cen-tral fixation itself, (2) the pursuit of moving stimulus patterns, and (3) the closely contigu-ous juxtaposition of visual, tactual and kinaesthetic processes which exhibit repeated corre-lation because of the nature of the physical environment and the organism's interactions with it. When these reinforcements are prevented, development is arrested at the level of the gross fixation response, which is probably chiefly monocular. Neuromotor processes

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other than visually guided ones, and governed in part by other sensory input, then become established, and once established may compete for years with the more adaptive processes that pattern vision makes possible. In a broad sense, this functional-developmental theory of binocular coordinations is in agreement with that of Keiner (3) as presented in his recent monograph.

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STUDIES ON RATE OF APPARENT CHANGE AS A FUNCTION OF OBSERVATION TIME IN A NEW TYPE OF DYNAMIC AMBIGUOUS FIGURE

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INTRODUCTION

There are indications on both theoretical and experimental grounds that the rate of apparent change (RAC) of an ambiguous figure has considerable potentiality as a method for measuring changes in sensitivity which occur in the central pathways of the visual system as a function of stimulation (1). Thus there is a need for adequate methods of measuring RAC, and for elucidation of the physiological process which is responsible for RAC. These are requirements which must be met before the practical potentialities of RAC can be fully realized. Thus the present experiments represent the continuation of a program of research to meet these requirements.

Historically the ambiguous figures which were first studied extensively were static figures which gave changes in apparent depth. These figures are unsatisfactory for experimental purposes, however, largely because the time of occurrence of the apparent change is often unclear. This difficulty was overcome by the introduction of dynamic ambiguous figures which gave simultaneous changes in apparent depth and apparent direction of movement. In such a figure any change in apparent depth is accompanied by a change in apparent direction of movement, so the moment of the change is always quite clear. The first ambiguous figure in this category was the Lissajous figure, which is a stimulus pattern produced on a cathode ray tube. This ambiguous figure was first used experimentally by Philip and Fisichelli (4). The author then introduced a figure produced by projecting the shadows of a rotating pattern of pins upon a screen, which is viewed from the other side (1). This stimulus pattern gives apparent changes quite similar to those which occur with the Lissajous figure, but for experimental purposes it has a number of advantages over the Lissajous figure. Both of these dynamic ambiguous figures, however, have one particular disadvantage. This is the occurrence of many kinds of extraneous movement, which may be defined as any kind of apparent movement other than the two primary kinds of apparent movement in the ambiguous figure. Of course extraneous movement increases the difficulty of interpreting the results, so it is desirable that such movement be minimized. Both the Lissajous figure and the dynamic figure developed by the author were perceptually three-dimensional, and most of the extraneous movements with these figures occur in perceptual depth. Thus a dynamic ambiguous figure has now been devised which is perceptually two-dimensional, giving changes in apparent direction of movement but no changes in apparent depth. It has proved possible with this figure to reduce the occurrence of extraneous movement. This figure also has a number of other advantages over previous stimulus materials, and these advantages will be enumerated in the discussion section of this paper.

The author has shown in previous experiments that there are many advantages in determining a curve which shows RAC as a function of observation time (1). Thus a curve of this type constitutes the basic measure used in the present experiments.

APPARATUS

The device for presenting the ambiguous figures is shown in Figure 1. This device was a modification of a special tachistoscope developed by Balco Research Laboratories.

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Apparent movement was produced by flash-
ing back and forth between two stimuli. One
stimulus was placed on the inside of the
back door of the tachistoscope, and was
seen directly through the 45° half-silvered
mirror. The other stimulus was placed on
the inside of the right door of the tachisto-
scope, and was seen reflected from the 45°
mirror. The ambiguous stimuli used in the
first two experiments are shown in Figure 2.
Part a and part b show the figures pre-
sented on the back and right fields, respec-
tively, of the tachistoscope. These figures
were accurately drawn with India ink on
white drawing board. The two figures were
aligned so that when presented simultaneous-
ly the fixation points were superimposed, and
the black segments of the one figure exact-
ly filled the spaces between the black seg-
ments of the other figure. When the two
figures were presented in alternation, of
course the subject saw a steady fixation
point. The alternation rate was 2.28 cps,
which produced smooth apparent rotation of
the segmented ring. The apparent direc-
tion of rotation with such a figure is ambig-

Figure 1. Scale drawing of apparatus as
seen from above.

uous, so the segmented ring appeared to rotate first in one direction
and then the other.

Preadaptation stimuli were used to preadapt all points of the
retina to the level produced by the ambiguous stimuli. This assured
that changes in RAC with observation time could not be attributed to
changes in adaptation. The preadaptation stimuli are shown in Fig-
ure 2. These stimuli were made and presented like the ambiguous
stimuli, so each retinal point was stimulated in a corresponding man-
ner by the preadaptation and ambiguous stimuli. Thus the preadap-
tation stimuli adapted each part of the retina to the same level as
that produced by the ambiguous stimuli, but the preadaptation stimuli
produced no apparent movement.

Figure 2. Am-
biguous stimuli and pre-
adaptation stimuli used
in Experiments 1 and 2.

The preadaptation stimuli were mounted on plates directly over
the ambiguous stimuli. These plates were spring loaded to hold
them back from the ambiguous stimuli. The preadaptation stimuli
were held in position for use by catches, and by pressing a switch the experimenter acti-
vated solenoids which released both catches simultaneously. This permitted the preadapta-
tion stimuli to swing out of position, thus exposing the ambiguous stimuli.

Each field of the tachistoscope was illuminated by two cold cathode fluorescent bulbs.
One bulb was mounted above the field, while the other was mounted below, and each bulb
was coiled back and forth to provide a large illuminating surface. Highly uniform illumi-
nation of the field was attained in this manner. The bulbs were operated from a stabilized
110 V. source, with the voltage across the bulbs controlled by a Variac at 60 V. The il-
lumination produced by the bulbs was slightly bluish in color, and the color temperature
was too high to be measured on the Eastman Color Temperature Meter. Luminance meas-
urements were made at the center of the stimulus field with a Luckiesh-Taylor Brightness
Meter. This instrument was mounted along the line of sight of the subject's right eye, and
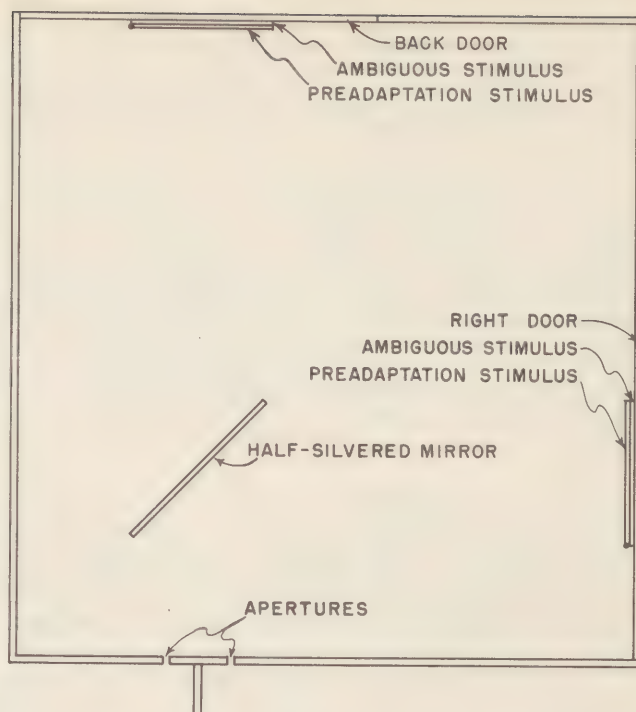
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special calibration cards were used to find the luminance of both background and figure. The luminance of the background proved to be 105. 3 ft-L, while that of the figure was 5. 2 ft-L. The transmittance and reflectance of the 45° half-silvered mirror were identical, so the luminances of the two fields were matched.

The cold cathode bulbs went on and off virtually instantaneously when power was applied and removed. Thus by applying power alternately to the two fields of the tachisto-scope, smooth alternation was attained between illumination of the two fields. Alternation was accomplished by an electrically controlled variable speed motor which carried a split rotating contact, each half of which completed the circuit to one field of the tachistoscope. The duration of a single exposure was the same for each field, and it proved possible to hold the alternation rate quite constant at 2. 28 cps. The speed control was kept in the experimental room, but the motor itself was removed to avoid the clocking of the rotating contact.

The subject's head was positioned so that a perpendicular from the fixation point of the stimulus figure on the back field of the tachistoscope would pass directly between the subject's eyes. The observation distance was 76. 5 cm., and the diameter of the ambiguous figure was 13 mm., so the ambiguous figure subtended a visual angle of 58'25''. Thus with steady fixation, stimulation was confined to the rod free area of the fovea.

The subject's head was held steady by an adjustable chin rest and forehead pads. In the front wall of the tachistoscope, 9 cm. from the subject's eyes, a separate aperture was mounted for each eye. These apertures were 7 mm. in diameter and were adjustable horizontally to allow for different interpupillary distances. These apertures restricted the size of the stimulus field. When making a measurement, the apertures were always adjusted so that they permitted the subject to see an area of uniform background of the stimulus figure, the border of which was concentric with the stimulus figure itself. Masking devices were used to prevent the subject from seeing any light from the tachistoscope except light passing through these two apertures. A septum was also mounted in the mid-sagittal plane of the subject, between the subject's face and the tachistoscope, to prevent the left eye from receiving stimulation from the right aperture and vice versa. A three-position eye selector was mounted in front of the apertures which made it possible to occlude the left aperture, right aperture, or neither aperture.

Results were recorded on two channels of a multi-channel Esterline-Angus recorder. This recorder was placed in a soundproofed box to eliminate the clocks of the solenoids. The subject was provided with a Microswitch to press each time an apparent change occurred. The experimenter also had a Microswitch to press each time the subject blinked. All testing was done in a darkroom, but there was enough light through the tachistoscope aperture to permit the experimenter to record blinks by watching the subject's right eye. Results were tabulated by merely counting the number of apparent changes and blinks recorded during successive 10 sec. intervals of observation time.

EXPERIMENT 1: INTEROCULAR TRANSFER OF INCREASE IN RAC

It was shown with the author's first dynamic ambiguous figure that there is essentially 100% interocular transfer of the increase in RAC which occurs with observation time (1). This finding demonstrates that the physiological process responsible for the apparent changes is common to the two eyes, and is located at least as far back in the visual system as the primary visual cortex. The ambiguous figure used in that study gave simultaneous changes in apparent depth and apparent direction of movement. It seemed desirable to determine first whether the principle of interocular transfer also applied to the new type of figure. Thus the first experiment was a determination of the interocular transfer of the increase in RAC which occurs with observation time.

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Subjects and Procedure

Four subjects were used, three men and one woman, whose ages ranged from 21 to 31 years. There were no histories of serious injuries or diseases involving the eyes, visual pathways, or brain. None of the subjects required glasses for the observation distance of the experiment. The subjects were chosen from a number of available subjects on the basis of preliminary tests. The criteria for choosing the subjects were high reliability of results and the presence of a relatively large increase of RAC with observation time. The first criterion served to exclude a considerable amount of error variance, and the second criterion served to magnify the size of the effect being measured. Thus the method of choosing subjects greatly increased the sensitivity of the test. The author served as one of the subjects, and of course he was aware of the expected results. The other three subjects, however, had no knowledge of the expected results. Since all subjects showed essentially the same amount of interocular transfer, there was no indication that expectation had any effect.

The same basic procedure was followed for all subjects. On the first day of measurement the subject was given his instructions. He was told to fixate the small dot in the center of the stimulus pattern as steadily as possible during both the preadaptation and test periods. Blinking was not prohibited, but it was requested that blinking be held to a minimum during the test period. It was specified that a passive attitude should be taken toward the ambiguous figure, and that the subject should not try to affect the kind of movement seen. The subject was instructed to keep track of the direction of apparent movement of the rotating wheel during the period of measurement, and to press his key each time there was a change in the kind of movement seen.

In making each measurement, the subject's eyes were first placed in correct position. Then the chin rest, forehead rest, and apertures were correctly adjusted. Measurements were made under two conditions, one experimental and one control. In describing these conditions, let us consider a subject in which transfer from the left to the right eye was measured. In the experimental condition the first step was one minute of binocular preadaptation, the second stop was one minute of measurement with the left eye, and the third step was one minute of measurement with the right eye. Prior to testing the preadaptation figures were set in position and the alternation motor was turned on. The subject was given a ready signal, and then the experimenter turned on the tachistoscope lights and started a stop watch simultaneously. Three seconds before the end of the one minute of preadaptation, a ready signal was given. Then the experimenter moved an occluder over the subject's right eye with one hand and threw a pair of switches with the other hand. These switches exposed the ambiguous figures and started the recorder. This initiated step two, the one-minute period of measurement with the left eye, and all changes required to initiate this period occupied only a fraction of a second. Three seconds before the end of step two another ready signal was given, and then the experimenter shifted the occluder from the right to the left eye. This initiated the one-minute period of measurement with the right.

A control condition was required because of possible small differences between the basic curves for left and right eyes. Also the right eye was dark adapting while the left eye was being measured, so the right eye was more dark adapted at the beginning of step three than the left eye was at the beginning of step two. The control condition was like the experimental condition, except that the left eye viewed the preadaptation stimulus instead of the ambiguous figure during step two. This made it possible to compare two curves for the right eye with the state of adaptation the same in both cases. The only difference was that the experimental curve was obtained after previous stimulation of the left eye with the ambiguous figure, while the control curve was obtained after previous stimulation of the left eye with only the preadaptation figure.

The first day of measurement was for practice, and two measurements were made under each condition. The two conditions were presented in an alternating order, with a minimum of 30 minutes between tests. This separation had been found in the earlier study to be sufficient to prevent the increase of RAC during one test from carrying over to the next. The practice day was followed immediately by Day 1 and Day 2 of testing. Half the subjects were tested in an experimental, control order on Day 1 and a control, experimental order on Day 2. On each day of testing five measures were made in the morning and five in the afternoon, with a minimum separation of 30 minutes between tests. This gave a total of ten measurements under each condition with each subject. It should be noted that the method of counterbalancing almost completely balanced out for each subject any systematic changes in RAC which may have occurred from morning to afternoon, or from Day 1 to Day 2. Since practice effects have proved negligible, the counterbalancing for each subject may be considered complete. In any case, the order of measurement on Day 1 and Day 2 was reversed with the other half of the subjects, giving a complete counterbalancing of experimental and control conditions for the group as a whole. Transfer was determined from the left to the right eye in two subjects, and from the right to the left eye in the other two subjects. None of the subjects were shown their results until the experiment was completed.

Results

The results of this experiment are shown in Table I and Figure 3. It may be seen from Table I that a high degree of transfer was obtained with each subject. The combined results with all subjects are shown in Figure 3. This figure shows the experimental and control curves which have been described. It also shows a continuous two-minute binocular

Table I

APPARENT CHANGES PER 10 SECONDS AS A FUNCTION OF OBSERVATION TIME
FOR THE THREE CONDITIONS OF MEASUREMENT USED IN EXPERIMENT 1.
RESULTS ARE SHOWN FOR ALL FOUR SUBJECTS*

Subject	Type of Measurement	Observation Time in Seconds						Average
		10	20	30	40	50	60	
E.N.	Eye 1 Experimental	7.6	12.1	17.0	16.6	22.9	19.0	15.9
	Eye 2 Experimental	11.1	20.1	23.5	20.6	22.6	23.8	20.3
	Eye 2 Control	8.8	14.0	17.7	18.7	19.6	23.3	17.0
I.S.	Eye 1 Experimental	9.9	12.4	12.5	12.9	12.8	13.0	12.2
	Eye 2 Experimental	11.6	12.9	12.8	13.1	13.5	13.2	12.8
	Eye 2 Control	10.7	11.6	12.0	12.5	13.0	12.8	12.1
K.B.	Eye 1 Experimental	1.3	3.8	4.6	5.1	6.4	7.0	4.7
	Eye 2 Experimental	5.2	8.1	8.0	7.0	7.4	7.2	7.2
	Eye 2 Control	1.2	3.7	4.8	5.8	6.4	7.2	4.8
W.S.	Eye 1 Experimental	1.5	1.5	1.6	2.1	3.4	5.2	2.6
	Eye 2 Experimental	3.6	4.0	4.0	4.3	4.3	4.2	4.1
	Eye 2 Control	1.6	2.4	2.3	2.8	3.1	4.1	2.7
Group Average	Eye 1 Experimental	5.1	7.4	8.9	9.2	11.4	11.0	8.8
	Eye 2 Experimental	7.9	11.3	12.1	11.2	12.0	12.1	11.1
	Eye 2 Control	5.6	7.9	9.2	10.0	10.5	11.8	9.2

*Each value in the body of the table is the average of 10 measurements.

curve, which will be discussed later in this section. All curves have been fitted visually to the plotted points, and it may be seen that good fits were obtained. The only striking exception is the first point on the Eye 2, Experimental curve. The first point on this curve exhibits a sharp drop in comparison with both the last point on the Eye 1, Experimental curve and all succeeding points on the Eye 2, Experimental curve. The drop was found consistently with all four subjects, so it is significant. All succeeding points on this curve, however, can be fitted rather well by a straight line. Since the last five points on the curve all indicate about the same amount of transfer, and since these points would be least affected by the experimental interruption of changing measurement from one eye to the other, they are believed to give the best measure of interocular transfer. It would be quite strange if the curve of transfer effect actually showed a large drop at the first point on the curve. Thus the curve which fits the last five points has been extended to the first point as well. The resulting curve is considered a rather accurate representation of the interocular transfer effect. The measured amount of transfer at the first point on the curve is believed less than the transfer effect at that point because of the interruption of measurement in changing from one eye to the other.

The drop of the first point on the Eye 2, Experimental curve was not found in the interocular transfer experiment with the rotating pins. It might be wondered, then, why it was found in the present experiment. With the rotating pins RAC was measured by the number of apparent changes per 30 seconds of observation time, but with the new figure RAC was measured by the number of apparent changes per 10 seconds. This means that the interruption of stimulation in changing from one eye to the other would be expected to have a considerably greater effect on the first point of the Eye 2,

Figure 3. Interocular transfer of increase in RAC as a function of observation time. Curves are average results of four subjects.

Experimental curve in the present experiment than in the first experiment. It is believed that this is the explanation for the difference between the results of the two experiments with regard to that point.

The Eye 2, Control curve is quite similar to the Eye 1, Experimental curve. These curves were obtained under identical conditions except that different eyes were measured in the two cases, and Eye 2 was slightly more dark adapted than Eye 1 at the beginning of measurement. The similarity of the two curves indicates the high reliability of measurement which was obtained in this experiment. The Eye 2, Control curve proved generally a little higher than the Eye 1, Experimental Curve. The statistical significance of this difference has not yet been tested, but it appears highly unlikely that the difference is significant.

The Eye 1, Experimental curve was only one minute long because preliminary tests showed that the RAC reached an approximate maximum after one minute. It is not clear from the points obtained under the experimental condition whether or not the Eye 2,
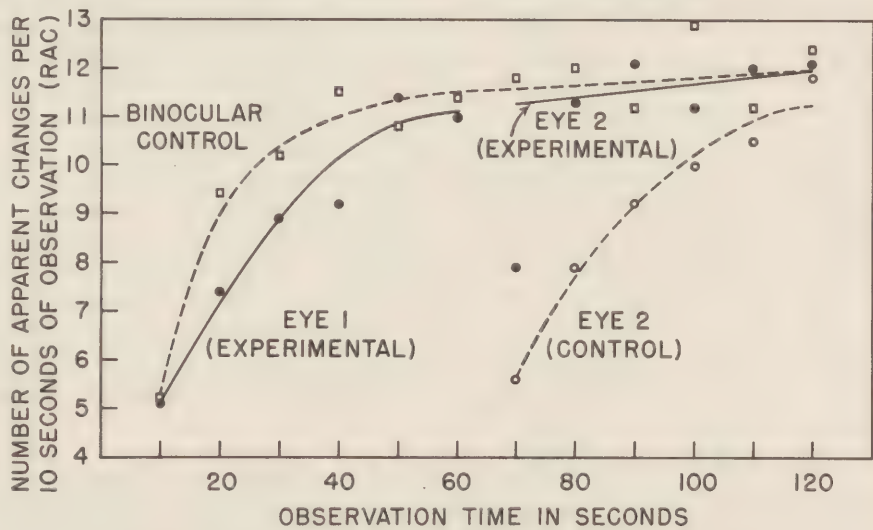
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Experimental curve coincides with the curve which would be obtained by a two-minute curve with continuous stimulation of the same eye. In order to show that the curve with continuous stimulation does reach an approximate maximum after one minute, a Binocular Control curve is also shown. This curve was obtained with the same ambiguous stimuli and same subjects. It is the curve which was determined in Experiment 2 under the condition of steady stimulation. This curve differs from the experimental curves in Figure 3 in that it was obtained with binocular rather than monocular stimulation, continuous stimulation rather than stimulation of first one eye and then the other, and in that it was determined at a different time. Curves on the same subjects have been found remarkably constant from time to time, so the time difference may be ignored. It may be noted that the Eye 2 Experimental curve is almost as high as the Binocular Control curve, in spite of the first two differences mentioned. Actually it is not quite as high as the Binocular Control curve, and this is as expected since it was shown in an earlier study that the RAC curve is higher with binocular than with monocular stimulation (1).

The results of this experiment are consistent with the hypothesis that 100% interocular transfer occurs, but the actual amount of transfer may be somewhat less than 100%. Thus the physiological process primarily responsible for apparent changes with the new ambiguous figure is one which is common to the two eyes. This means that the process must be located at least as far back in the visual system as the primary visual cortex.

The difference between the Eye 1, Experimental and the Binocular Control curve gives a measure of binocular summation with the present ambiguous figure. Binocular summation was found with the earlier ambiguous figure, and in that study the binocular curve was higher than the monocular curve throughout its entire extent. In this study the fitted curves show the binocular curve to be above the monocular curve throughout the central part of the curve, but the initial points are essentially identical and the curves appear to come together again at the end. The striking differences between the two curves are that the binocular curve has a greater slope, and the approximate maximum in the binocular curve is attained after a shorter amount of observation time. It may be seen from Table I and Table II that the relation between binocular and monocular curves was rather consistent in the four subjects.

Both experiments with binocular and monocular stimulation have shown that binocular summation occurs. The exact relation between the curves was somewhat different in the two experiments, however, so it might be wondered which relation is correct. It is believed that the present experiment gives the most accurate determination of the relation between binocular and monocular curves. The subjects in the earlier experiment were not selected on the basis of reliability, but the subjects in this experiment were selected on that basis. Thus this experiment gave more reliable results. Further evidence that accurate results were obtained in the present experiment is the high consistency between the results with binocular summation and the results obtained when strength of stimulation was varied in other ways. The other methods of varying strength of stimulation will be reported in the next two experiments, and the significance of binocular summation will be treated in the discussion section of this paper.

Blink rate was recorded in this experiment, and in succeeding experiments, to take into account any effects of blink rate upon RAC. There was no apparent effect, however, of blink rate upon RAC. Thus if there is an effect it is negligible, so the results of blink rate are not being reported.

EXPERIMENT 2: RAC AS A FUNCTION OF OBSERVATION TIME
UNDER CONDITIONS OF STEADY AND DISPERSED STIMULATION

Experiment 1 indicates that the physiological process primarily responsible for apparent changes in the new dynamic ambiguous figure is located at least as far back in the

visual system as the primary visual cortex. The next question concerns the mechanism by which RAC is controlled. Fisichelli varied Lissajous figures in several ways to change the amount of stimulation per unit time and per unit area which was delivered to the retina by the ambiguous figure. He found that whenever he increased the stimulation per unit time and per unit area which was delivered to the retina, the RAC was increased (3). It was desired to test this principle with the new ambiguous figure and also to determine accurately the relation between the curves obtained with two highly different rates of stimulation.

Subjects and Procedure

The same subjects were used in this experiment as in Experiment I. The general procedure was also like that of Experiment I, the only major difference being in the conditions of measurement used. In this case the conditions of measurement have been designated as Steady Stimulation and Dispersed Stimulation. Under the condition of Steady Stimulation, a one-minute period of binocular preadaptation was followed immediately by a two-minute period of measurement. During the period of measurement, the subject viewed the ambiguous figure binocularly and fixated steadily the fixation point in the center of the figure. The condition of Dispersed Stimulation was like that of Steady Stimulation, except for the instructions on fixation. In order to obtain Dispersed Stimulation, the subject was instructed to look directly at one of the segments of the ambiguous figure and to always follow this segment with his eyes in whatever direction the ring appeared to be rotating. Thus with fixation of the center point the ambiguous figure stimulated relatively steadily the same part of the retina throughout the two-minute period of measurement. In the other condition, however, the pattern of retinal stimulation was one in which the ambiguous figure rolled around the center of the fovea. The total amount of stimulation delivered to the retina by the ambiguous figure may be considered the same in both cases. In the condition of Dispersed Stimulation, however, the stimulation was distributed over a larger area of retina and the amount of stimulation per unit time delivered to each part of the retina was reduced. It is obvious that the amount of stimulation per unit time and per unit area of retina is markedly different in the two conditions, so this may be expected to be a good method for determining the effect of different stimulation rates on RAC curves.

Results

The results are shown in Table II and Figure 4. Table II shows that the relation between the two curves was highly consistent in all four subjects, and Figure 4 shows the combined results of all subjects. The condition of Steady Stimulation produced an increased initial point on the curve, a greater slope, and a larger increase in RAC with observation time. A much shorter time was also required to attain an approximate maximum, since this point was attained in about 40 seconds with Steady Stimulation but it appears not to have been attained even after two minutes with Dispersed Stimulation. Since the curve for Dispersed Stimulation still seems to be increasing slightly at the end of two minutes, it is impossible to determine from this data whether or not the curves would come together with a very long observation time. Longer observation times were not used because it is difficult for the observer to sustain accurate observation over a long period. By the end of two minutes both curves have approximately the same slope, however, and the difference between the two curves is very great. Thus it seems highly unlikely that the curves would merge together even with a very long observation time.

The results of this experiment indicate that when a subject is used as his own control, the RAC curve is strongly determined by the amount of stimulation per unit time and per unit area which is delivered to the retina by the ambiguous figure. Large differences in stimulation rate were used, and the relation between the two RAC curves was quite distinct. Thus this experiment is also considered to give an accurate determination of the relation which may be expected between two curves obtained with different stimulation rates.
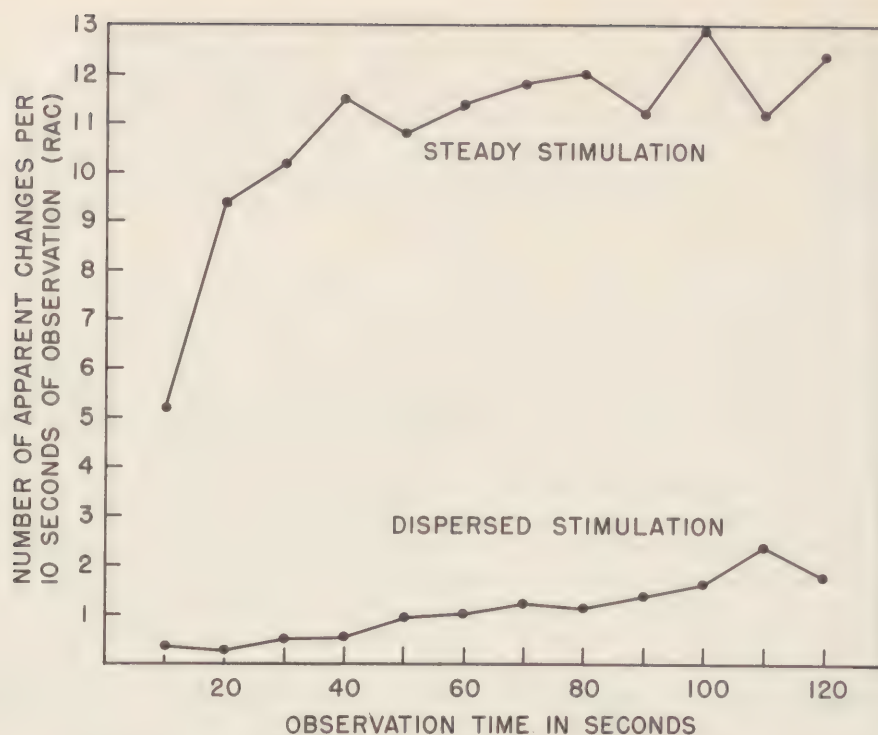
Figure 4. RAC as a function of observation time under conditions of steady and dispersed stimulation. Curves are average results of four subjects.

Table II

APPARENT CHANGES PER 10 SECONDS AS A FUNCTION OF OBSERVATION TIME, USING STEADY AND DISPERSED STIMULATION. RESULTS ARE SHOWN FOR ALL FOUR SUBJECTS*

| Subject | Type of Stimulation | Observation Time in Seconds | | | | | | | | | | | | Average |
		10	20	30	40	50	60	70	80	90	100	110	120	
E.N.	Steady	6.4	17.6	20.5	22.4	19.8	22.4	23.2	22.9	20.5	25.2	19.6	23.1	20.3
	Dispersed	0.0	0.0	0.5	0.6	1.4	1.3	2.1	1.9	3.2	3.1	5.8	3.4	1.9
I.S.	Steady	11.0	13.2	13.1	13.2	13.6	13.7	13.6	13.3	12.8	13.8	13.3	14.0	13.2
	Dispersed	1.4	0.9	0.7	1.1	1.1	1.2	1.6	1.4	1.3	1.9	1.7	1.6	1.3
K.B.	Steady	1.9	5.0	5.4	7.5	7.2	7.1	6.7	7.5	7.2	7.3	7.6	7.9	6.5
	Dispersed	0.0	0.2	0.1	0.3	0.4	0.7	0.2	0.5	0.3	0.6	0.7	0.6	0.4
W.S.	Steady	1.5	1.8	1.8	2.8	2.8	2.4	3.9	4.4	4.1	5.2	4.5	4.8	3.3
	Dispersed	0.0	0.1	0.7	0.2	0.9	0.9	1.1	0.8	0.8	1.0	1.4	1.6	0.8
Group Average	Steady	5.2	9.4	10.2	11.5	10.8	11.4	11.8	12.0	11.2	12.9	11.2	12.4	10.8
	Dispersed	0.4	0.3	0.5	0.6	1.0	1.0	1.2	1.2	1.4	1.6	2.4	1.8	1.1

*Each value in the body of the table is the average of 10 measurements.

EXPERIMENT 3: RAC AS A FUNCTION OF OBSERVATION TIME WITH TWO LEVELS OF CONTRAST SENSITIVITY

Since the RAC curve is strongly determined by the amount of stimulation per unit time and per unit area which is delivered to the retina by the ambiguous figure, then the curve should be influenced not only by stimulus variables but also by the sensitivity of the visual system. This raises the possibility that the RAC curve can be used as a measure of visual sensitivity. This possibility was tested in the present experiment by using two levels of preadapting luminance to obtain two levels of contrast sensitivity for the ambiguous figure. The effect of these two levels of contrast sensitivity upon the RAC curve was then determined.

Subjects and Procedure

Three of the subjects from the previous experiments were also used in this experiment. Subject E.N. was no longer available, however, and was replaced by A.D. This new subject met all the criteria described in Experiment 1, and he was thoroughly practiced in making measurements prior to beginning actual tests. All four subjects in this experiment were males, ranging in age from 22 to 37 years.

Certain changes were made in the apparatus for this experiment. A new set of ambiguous stimuli was developed, and these are shown in Figure 5. This ambiguous figure was essentially like the first one, except that it looked more like a rotating solid wheel than a rotating ring. It is obvious that fixation with the first figure is very critical, and the new figure was designed partly to make fixation less crucial. The new figure also has the advantage for this experiment of being a white figure against a black background. This makes it easier to obtain a preadapting brightness which is much greater than the background brightness of the figure. The ambiguous stimuli were made by drawing them with India ink on white cardboard at four times the final size. Then they were photographed and printed with reverse contrast on matte paper. The size reduction in printing made it possible to obtain very accurately made stimuli.
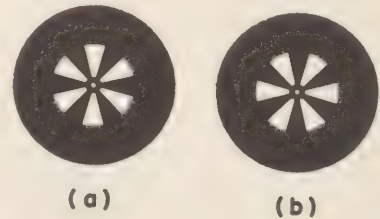

(a) **(b)**

Figure 5. Ambiguous stimuli used in Experiment 3.

It has been demonstrated by Craik (2) that differential brightness sensitivity of the visual system is maximum when the eye is preadapted to a background luminance equal to that against which a brightness difference is to be discriminated. When a higher preadapting level is used, contrast sensitivity is reduced. This means that contrast sensitivity for the ambiguous figure is maximum when the preadapting brightness is equal to the background luminance of the ambiguous figure, and when a higher preadapting luminance is used, contrast sensitivity for the ambiguous figure is reduced. The two preadapting luminances were obtained by using the two different sides of the tachistoscope. On the back field a preadapting stimulus was mounted which was photographically produced and just like the background of the ambiguous stimuli. This preadapting field contained a small red fixation point, and it was illuminated only by the fluorescent bulbs which were also used to illuminate the back ambiguous stimulus. The right preadapting field consisted of a piece of white cardboard, also containing a small red fixation point. This field was illuminated by the fluorescent bulbs for the right side of the tachistoscope. In addition, a General Electric 150 W. projector spot lamp was mounted in the tachistoscope and directed toward the center of the right preadapting field. This greatly increased the luminance of the field.

The luminance of the background of the ambiguous figure was 5.14 ft-L, and the luminance of the ambiguous figure itself was 96.7 ft-L. The luminance of the back preadapting field was 5.14 ft-L, and the luminance of the right preadapting field was 2200 ft-L. These

There were several differences between results with the two different preadapting luminances. When the higher contrast sensitivity was produced, the initial point on the curve was higher, the slope of the increase in RAC with observation time was greater, and the maximum point in the curve occurred at a shorter observation time. These effects of increased contrast sensitivity all correspond to effects which were found when Steady Stimulation was used instead of Dispersed Stimulation. The relations between the two curves were not exactly the same, however, in both experiments. In Experiment 2 Steady Stimulation gave a larger absolute increase in RAC with observation time, and it appears unlikely that the curves would merge even with a very long observation time. In this experiment, however, the two curves came close together after about 70 seconds of observation time, and thereafter they
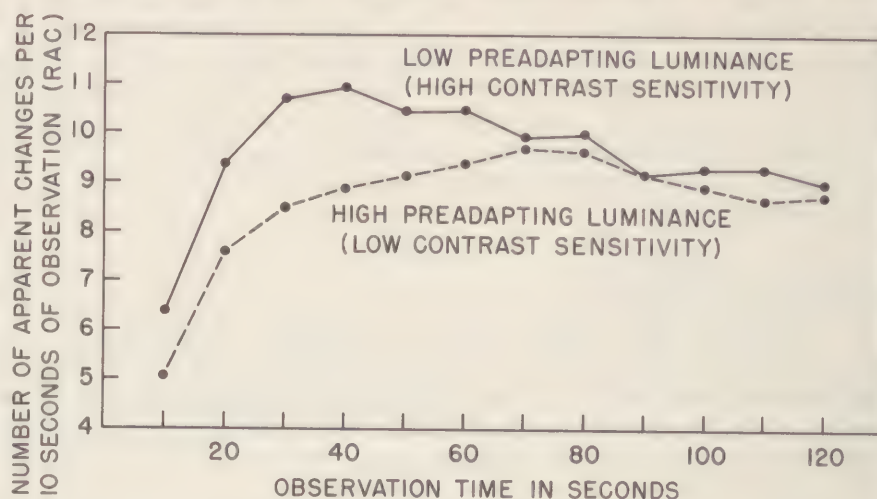

Figure 6. RAC as a function of observation time with two levels of preadapting luminance (contrast sensitivity). Curves are average results of four subjects.

remained close together. This difference between results in the two experiments can be explained quite simply. In Experiment 2 the difference in stimulation rate was maintained throughout the two-minute test period. Hence the difference between the two RAC curves would be expected to persist throughout the test period. In this experiment, however, the loss in contrast sensitivity which was produced by the high preadapting luminance was gradually dissipated during the test period. Thus the two curves would be expected to come closer together during the test period, and this actually occurred. In summary, the effects of different stimulation rates were quite comparable in Experiments 2 and 3, although in Experiment 2 the stimulation rate was altered by varying the pattern of stimulation on the retina, and in Experiment 3 the stimulation rate was altered by varying contrast sensitivity of the visual system. The difference between results obtained with the two variables are simply explained on the basis of the constancy with which the difference in stimulation rate was maintained throughout the test period.

The curves in Figure 6 show a definite drop at the end, and this drop deserves particular mention. Such a drop was not found with the first four subjects used in this series of experiments, but it was definitely present in the subject who was used for the first time in Experiment 3. Hence the drop does not seem to be a typical finding, but it was found in one subject. The drop which occurs in the combined curves of Figure 6 was contributed entirely by this subject.

DISCUSSION

The ambiguous figure used in this study is believed to have several advantages for experimental work over dynamic ambiguous figures which have been developed previously. First, fixation with this figure seems easier than with previous dynamic ambiguous figures. The reason is probably that apparent movement with this figure occurs symmetrically around the fixation point. Second, it is possible with this figure to confine stimulation to a small area of the retina. In the present experiments, for example, stimulation was confined to the rod-free area of the fovea when the center of the figure was fixated. Third,

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preadapting luminances are indicated by Craik's data to give a considerable difference in contrast sensitivity for targets presented against the background brightness of the ambiguous figure. The two preadapting fields were slightly different in color. The low luminance preadapting field was slightly bluish, and the high luminance field had a color temperature of 2900° K. Both fields were illuminated with the same kind of fluorescent lighting, however, and one field merely had the illumination of the spot lamp added. Thus a lowered contrast sensitivity may definitely be expected with the higher preadapting luminance.

All measurements were made with the subject's right eye, and a 2 mm. artificial pupil was used. This served to hold pupil size constant under the two experimental conditions, in spite of the different levels of preadapting luminance.

The procedure in this experiment was also like that in Experiment 1, except for the experimental conditions used. When making a measurement with the low level of preadapting luminance, the subject was first placed in position and the room lights were turned off. The back preadapting stimulus was set in position, and then the preadapting illumination was turned on for three minutes. At the end of three minutes the experimenter simultaneously released the preadapting field, started the alternation motor, and started the recorder. This started the test period, which lasted for two minutes. When the high level preadapting stimulus was used, the procedure was essentially the same. In this case the right preadapting field was used. The spot lamp was turned on at the same time as the right fluorescent lamps at the beginning of preadaptation, and this spot lamp was turned off at the end of preadaptation.

Results

The combined results of all four subjects are shown in Figure 6, and the results of each subject are shown in Table III. The relation between the two curves was quite consistent for all subjects.

Table III

APPARENT CHANGES PER 10 SECONDS AS A FUNCTION OF OBSERVATION TIME, USING TWO LEVELS OF PREADAPTING LUMINANCE (CONTRAST SENSITIVITY). RESULTS ARE SHOWN FOR ALL FOUR SUBJECTS*

Subject	Preadapting Luminance	Observation Time in Seconds												Average
		10	20	30	40	50	60	70	80	90	100	110	120	
A.D.	5.14 ft-L	5.1	12.3	15.5	17.4	14.8	14.1	12.6	12.3	9.7	9.9	9.4	9.1	11.8
	2200 ft-L	4.7	8.8	11.6	12.2	13.1	13.6	13.0	12.5	10.1	9.3	8.3	8.9	10.5
I.S.	5.14 ft-L	12.7	13.9	15.1	14.3	14.1	14.7	13.9	14.6	14.4	14.5	14.4	14.2	14.2
	2200 ft-L	11.4	13.1	13.9	13.8	13.2	13.7	13.4	13.6	14.0	13.8	14.2	13.9	13.5
K.B.	5.14 ft-L	6.2	9.7	10.7	9.9	10.3	10.2	10.0	10.1	9.6	9.9	10.6	9.5	9.7
	2200 ft-L	3.0	6.8	6.9	8.2	8.3	8.4	9.6	9.3	9.2	9.5	9.3	9.4	8.2
W.S.	5.14 ft-L	1.5	1.6	1.4	2.1	2.6	2.9	3.2	3.0	3.2	2.9	2.9	3.2	2.5
	2200 ft-L	1.2	1.7	1.6	1.4	2.0	1.9	2.8	3.2	3.6	3.2	2.9	2.9	2.4
Group Average	5.14 ft-L	6.4	9.4	10.7	10.9	10.4	10.5	9.9	10.0	9.2	9.3	9.3	9.0	9.6
	2200 ft-L	5.1	7.6	8.5	8.9	9.2	9.4	9.7	9.6	9.2	9.0	8.7	8.8	8.6

*Each value in the body of the table is the average of 10 measurements.

the interpretation of results with this figure is simpler than with previous dynamic ambiguous figures. In previous dynamic ambiguous figures there are simultaneous changes in apparent depth and apparent direction of movement. Hence it is impossible to know whether the perceptual changes which occur are determined primarily by changes in apparent depth or changes in apparent direction of movement. With the present figure, however, only changes in direction of apparent movement occur. Fourth, there is much less extraneous movement with this figure than with the two previous kinds of dynamic ambiguous figures. This makes interpretation of results simpler, and it probably increases reliability of measurement.

Results of experiments with the new dynamic ambiguous figure show that the basic principles which hold for previously used dynamic ambiguous figures also hold for the new figure. The increase in RAC which occurs with observation time, using monocular stimulation, transfers essentially 100% to the other eye. It does not seem possible for such a high degree of interocular transfer to occur except on the basis of a physiological process which is in a final common pathway for the two eyes. The first point in the visual system at which such a final common pathway might exist is the primary visual cortex. Thus the physiological process which is primarily responsible for the apparent changes in the ambiguous figure must be located at least as far back in the visual system as the primary visual cortex. It might be even farther back, but discussion may be simplified by assuming that the process is located in the primary visual cortex.

With regard to the quantitative rules governing RAC, it should be noted first of all that there are large and stable differences between the RAC curves of different subjects. When each subject is used as his own control, however, the RAC curve is determined largely by the amount of stimulation per unit time and area which is delivered to the retina by the ambiguous figure. This is shown clearly by Experiment 2, and the results of Experiment 2 are stated in retinal terms only because it is the retinal stimulation which can be most accurately specified. An increase in retinal stimulation probably results in an increased stimulation throughout the visual system, and it is important to know at what level of the visual system the stimulation rate actually produces its effect on RAC. Since the physiological process responsible for the apparent changes is located at least as far back as the primary visual cortex, it is highly probable that the point in the visual system where stimulation rate produces its effects on RAC is also at least as far back as the primary visual cortex. If this hypothesis is correct, then the RAC curve is largely determined by the stimulation per unit time and area which is delivered to the primary visual cortex by the ambiguous figure. Stimulation rate at the visual cortex can be altered by stimulus variables, but it should also be altered by changes in sensitivity of the visual system occurring at any level up to and including at least the primary visual cortex. This means that if the hypothesis is correct, then RAC curves can be used to measure changes in sensitivity which occur at the photochemical level, and also changes in neural sensitivity occurring at any level of the visual system up to and including at least the primary visual cortex. The most important point is that according to the hypothesis RAC curves could be used to measure changes of neural sensitivity in the visual system of the intact human being. Since the visual system may be regarded as a sample of the central nervous system, RAC curves may also provide a method for measuring more general changes in sensitivity of the central nervous system.

Two kinds of evidence were obtained in these studies which bear upon the above hypothesis. Experiment 3 showed that changes in contrast sensitivity of the visual system affect the RAC curves in a manner quite comparable to the effects which occur when stimulation rate is altered by changing the stimulus pattern on the retina. The finding that the binocular RAC curve is higher than the monocular curve also provides evidence for the hypothesis. With binocular viewing there is an increased stimulation rate which might occur as early as the optic chiasma, and which could definitely occur at the visual cortex. There is no known mechanism, however, whereby it could occur prior to the optic chiasma. Since

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the binocular RAC curve proved higher than the monocular curve, this means that increased stimulation rate can increase RAC even when the increase in stimulation rate does not occur prior to the optic chiasma.

Drug studies are now being planned to determine whether RAC curves can be used to measure purely neural changes in sensitivity. A few observations along these lines have already been made by other authors, and these observations support the basic hypothesis.

In summary, the research reported here indicates that the RAC curve has considerable potentiality as a basic visual measure. It also indicates that there are a number of potential military applications. There are military situations which produce physiological conditions, such as hypoxia, in which loss of sensitivity in the central nervous system is the limiting factor in the maintenance of performance. It may be possible to use RAC curves to determine the effects of hypoxia upon neural sensitivity, and hence to set physiological tolerance limits for hypoxia and similar variables. Another application of the technique is to explore the possibility of fatigue effects in the central pathways of the visual system. The RAC curve may also prove valuable in determining the usefulness of drugs and other methods for preventing losses in sensitivity of the central nervous system under specified military conditions. Studies along all of these lines are now being initiated.

SUMMARY AND CONCLUSIONS

1. A new kind of dynamic ambiguous figure has been developed. This figure is perceptually two-dimensional, giving changes in the apparent direction of movement but no depth effects. This figure has a number of advantages over previous dynamic ambiguous figures for experimental work.

2. The basic measure used in these experiments is a curve showing rate of apparent change (RAC) as a function of observation time.

3. The increase in RAC as a function of observation time, using monocular stimulation, proved to transfer essentially 100% to the other eye. Thus the physiological process primarily responsible for the apparent changes is one which is common to the two eyes. This means that the process is located at least as far back in the visual system as the primary visual cortex.

4. Large and stable differences were found between the RAC curves of different subjects.

5. Two conditions of fixation were used to obtain two rates of stimulation per unit area delivered to the retina by the ambiguous figure. With the higher rate of stimulation the initial point on the RAC curve was higher, the slope was greater, the amount of increase in RAC with observation time was greater, and the approximate maximum in the curve was attained after a shorter observation time. Thus when a subject is used as his own control, the RAC curve is strongly determined by the amount of stimulation per unit time and area which is delivered to the retina by the ambiguous figure.

6. Two conditions of contrast sensitivity for the ambiguous figure were obtained by using two preadapting luminances. The effect of increasing contrast sensitivity of the eye, proved quite comparable to the effect of increasing stimulation rate by altering the pattern of retinal stimulation.

7. Binocular and monocular RAC curves were compared, and binocular summation was found.

8. On the basis of the above results it seems highly probable that, when a subject is used as his own control, the RAC curve is strongly determined by the amount of stimulation

per unit time and area which is delivered to the primary visual cortex by the ambiguous figure. If this hypothesis is correct, then the RAC curve can be used to measure changes in sensitivity occurring at any level of the visual system up to and including at least the primary visual cortex. The important point is that according to the hypothesis changes in purely neural sensitivity could be measured in the intact human being. Thus the RAC curve seems to have considerable potentiality as a basic visual measure. A number of potential military applications are discussed.

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PHOTOPIC THRESHOLD PROPERTIES FOR RETINAL PERIPHERY*

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ABSTRACT

An account of data concerning incremental intensity thresholds (uniocular) for two trained observers, with the small ($0^\circ.5$) test-image at 10° temporally from fovea. The photopic and scotopic functions are quite distinct; the scotopic is always "duplex," probably indicating that there are two main types of neural connections--respectively for a smaller and a larger receptive unit—over the scotopic range. There is usually some interaction (more than mere summation) of effects in the range of light-adaptation level where scotopic and photopic contours join (not found in the case chosen for Figure 1).

At fovea, as for the peripheral photopic contour, the incremental I function is simplex (contra Stiles). The plotted mean incremental thresholds are values for λ', the 50 per cent positive ("seen") response level in adequately determined $\psi(\underline{S})$ seeing-frequency curves. At fovea, as elsewhere shown, $\sigma_{\log \Delta I}$ declines sharply with low levels of adapting background I_1, homochromatic or heterochromatic. It then rises sharply when the degree of light-adaptation is such that 50-60 per cent of the initial sensitivity has been "adapted out." This is explicable on statistical grounds. At the very highest background levels $\sigma_{\log \Delta I}$ tends to rise (glare effect?).
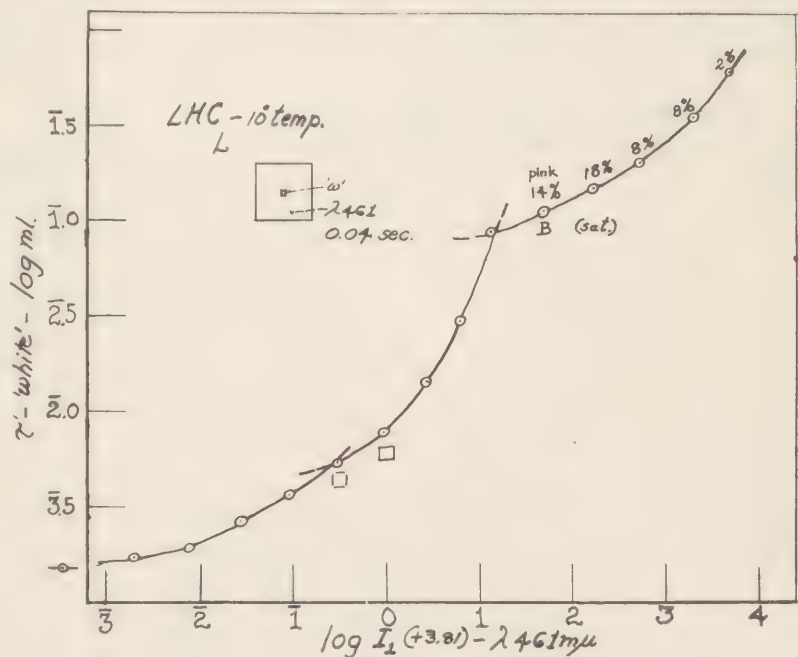

Figure 1. Mean $\Delta I(\lambda')$ from $\psi(\underline{S})$ curves for a "white" $0^\circ.5$ square test-image on an adapting field of $\lambda 461$, 15° square. Test at 10° temporally, left eye LHC, exposure-time 0.04 sec. To illustrate compound character of the scotopic curve (mild in this instance), and the "cutting off" of the photopic curve. (The level of appearance of the outline of the background is indicated below the curve; the first appearance of proper color in the background is at $\underline{B}$; above "(sat.)" the background became less saturated. Under various circumstances a certain percentage of seen "white" flashes are reported as red or pink; in the present case such values are noted above the curve.)

Peripherally (Figure 2) this picture is repeated for each of the three segments of the complex contours such as are seen in Figure 1.

Employing a large number of relationships between $\lambda\lambda$ for light-adaptation and for test, it is possible to obtain quantitative information about the capacities of various spectral regions to induce light-adaptation with respect to the test-lights, and thus to investigate the degree of similarity between foveal and extra-foveal photopic excitabilities. The indices are independent of the presence of irrelevant absorbers.

Since each segment of the incremental threshold contour is well described by $1/\lambda'$ vs. $\log I_1$ as a probability integral, it is possible for the extra-foveal photopic sections to estimate the lower λ' asymptote quite accurately, weighted by all the data of this segment. Thus even when "cut off" (as in Figure 1) or obscured by interaction complications, the analytical lower asymptotes can be studied in relation to λ, exposure-time, O_2 respired, and the like.

As function of λ the peripheral (homochromatic) "cone threshold" does not have quite the form derived from ordinary estimates of color thresholds, since the incidence of color in the test flashes is usually (but not necessarily) well above the asymptotic λ'.

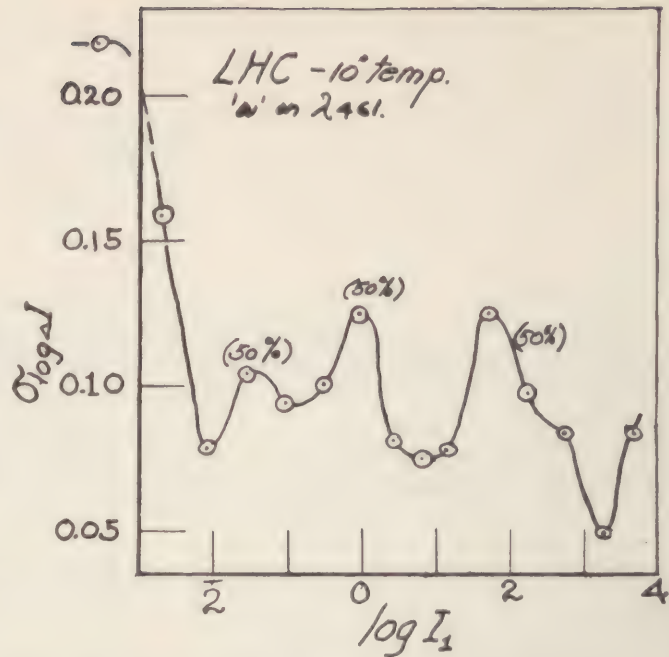A number of further points emerge in the full papers now actively in preparation.

Figure 2. For the $\psi(\underline{S})$ data of Figure 1 $\sigma_{\log \Delta I}$ is plotted against $\log I_1$. Discussed in the text.

EFFECTS OF COLORED ADAPTATION STIMULI UPON THE HUMAN ELECTRORETINOGRAM

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Whenever a strong flash of light impinges upon the retina a series of electrical changes known as an electroretinogram is produced. These changes, which may now be routinely investigated even in the human eye, are of interest because they provide a technique for obtaining physiological measures of phenomena which otherwise could be examined only psychophysically. The nature of electroretinogram may be seen in Figure 1. When the eye is well dark-adapted, a recording exhibiting prominent A, B, and C waves as shown in the upper part of the figure is obtained. If the eye is incompletely dark-adapted, however, an additional wave may appear. This is the wave marked X in the bottom tracing of Figure 1. When the eye is well light-adapted, the B wave disappears leaving only the X wave and a diminished A wave. On the basis of rather extensive experimentation (1-3), it has been clearly demonstrated that the X wave is associated with photopic activity of the retina and that the B wave is primarily scotopic. Although it would be anticipated that the X and B wave components would be differentially affected by exposure to selectively filtered light, no previous study of the effects of color adaptations upon these components has been made.
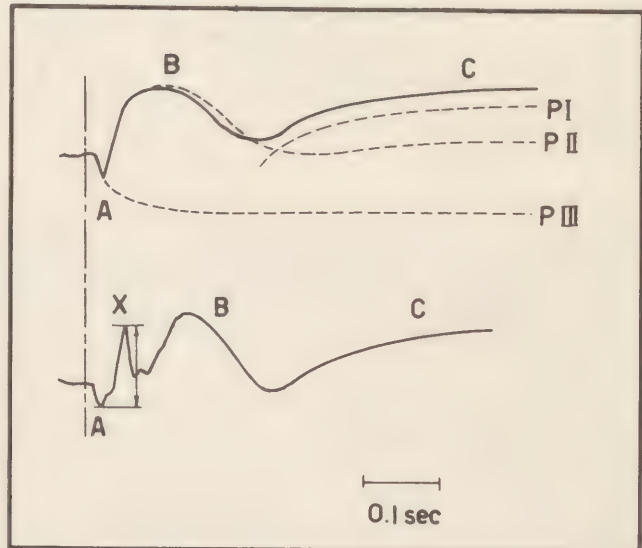

Figure 1. Appearance of the human ERG. An upward deflection indicates positivity of the cornea. The upper example is typical of the completely dark-adapted eye. Dashed lines show Granit's analysis of the ERG into three components (5). Lower tracing shows additional waves which may be seen when the eye is incompletely dark-adapted. The X wave remains distinct from the B wave only with red stimuli. If the eye is light adapted, the B wave disappears and amplitude of the X wave is reduced. The double arrow in the lower figure illustrates the height measurement used in the present paper.

In the present experiment the effects of color adaptation have been investigated under two conditions. In the first, the eye was held at a low level of light adaptation so that both X and B waves appeared in the recordings as shown in the lower record of Figure 1. The attempt was made to selectively remove either the photopic X wave or the scotopic B wave through adaptation to appropriate bands of colored light. In the second phase of the experiment, the level of light adaptation was increased so that X waves alone could be seen in the recordings. The effects of color adaptation upon the relative spectral sensitivity of this component were then investigated.

APPARATUS

Apparatus used in the study of the electroretinogram consists of two main parts; one of these, a stimulating system, is used to deliver flashes of selectively filtered light to the eye, and the other, a recording system, is used to trace the electrical response.

Operation of the stimulation equipment is sketched in Figure 2. For purposes of adaptation the apparatus presented the observer with a uniform white adaptation surface
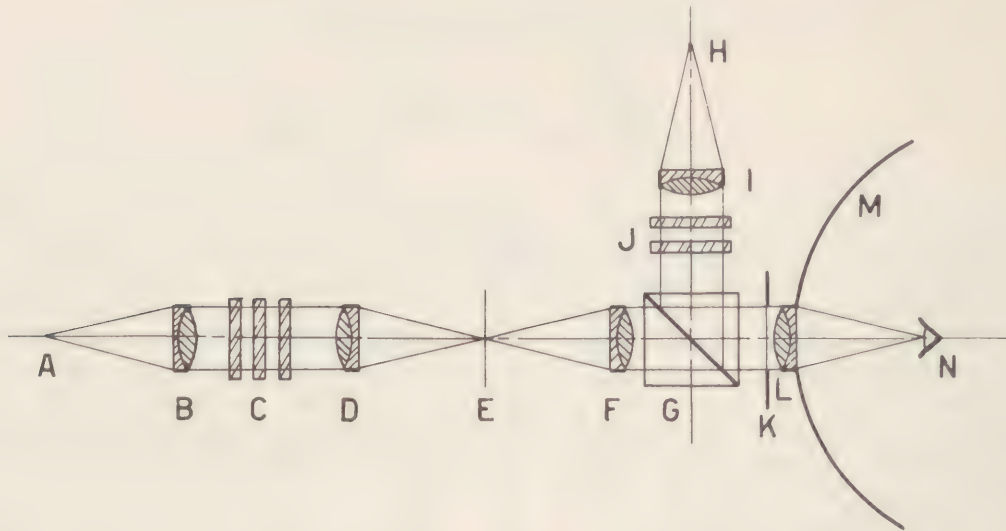

Figure 2. Sketch of stimulator optics. A, main source lamp; B, D, F, I, L, lenses; C, J, interchangeable filters; E, shutter; H, adaptation source lamp; G, beam splitter; K, fixation reticle; M, surround adaptation screen; N, observer's eye. Not to scale.

filling most of the visual field together with a colored adaptation patch in the center. To elicit the electroretinogram, single flashes of selected wave length and intensity were superimposed upon the colored central region. Both test flashes and colored adaptation stimuli were administered through a Maxwellian view of the final stimulator lens and subtended 30° at the observer's pupil. Light for test flashes traveled the length of the system as already described in the literature (2, 4). A beam-splitting cube located immediately behind the final lens introduced collimated adaptation light from an auxiliary optical system. The white "surround" field was produced by a matte screen illuminated with projected light. The surround was mounted concentrically about the last lens of the stimulator.

Wavelength and intentsity of both adaptation and stimulus lights were changed through insertion of calibrated color and neutral density filters in the appropriate light paths. The main source lamp, an 18 amp. DC tungsten ribbon filament, was maintained at a
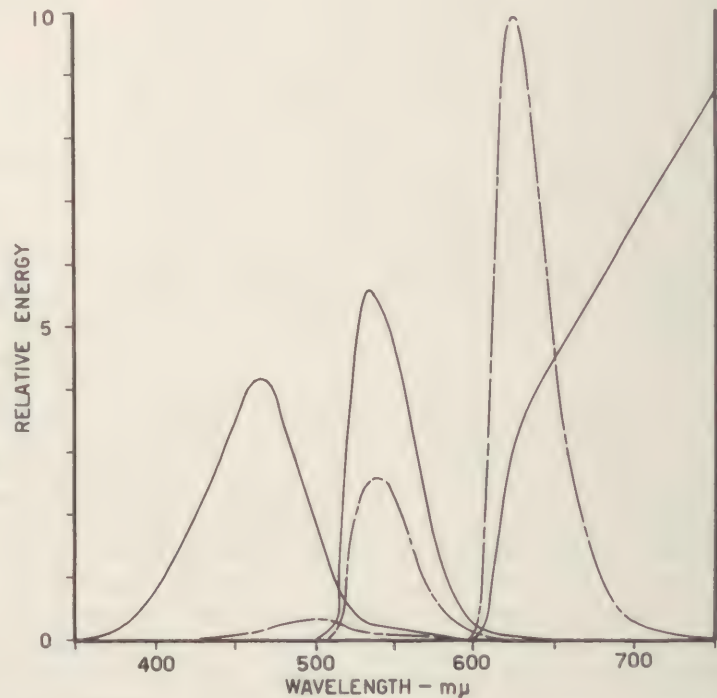

Figure 3. Spectral composition of colored adaptation stimuli. Solid lines are in units of relative energy. The red energy has been plotted to one-half scale. Dashed lines are in units of relative luminous flux as based upon the ICI photopic luminosity function. Red field luminance is estimated to be about 250 ft-L; green field, 81 ft-L; and blue field, 40 ft-L.

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constant temperature of 2500° K through adjustment of a rheostat in the supply circuit. A coiled filament lamp at 3300° K was the source for the colored adaptation beam. The spectral distribution of the three colored adaptation stimuli is given in Figure 3.

The eye was kept in alignment with the stimulator through the use of a "biting board" and fixation. A cross-hair reticle behind the last lens provided for central fixation. The duration of test flashes was set at 0.01 second. Responses were "picked up" from the eye with an electrode supported in a contact lens. Conventional equipment was used for amplification and recording.

PROCEDURE

For all experiments the eye was first adapted to the white surround field together with a colored central field. Recording was begun with the adaptation lights remaining lighted. Test flashes were separated by one-minute intervals. Usually no more than 60 test flashes could be delivered in a single experimental session. The procedure put a considerable strain upon an observer inasmuch as it required continuous fixation of the colored adaptation field. Furthermore, when more than one condition of adaptation was investigated in a single day, it was necessary to repeat the preadaptation procedure. The experiment was conducted in two parts.

Part 1. This part was designed to selectively eliminate either the X wave or the B wave from the tracings. Records were first obtained in which red test flashes produced a clear separation of X and B waves. Such tracings, it was found, are produced when the surround has a luminance of 0.006 ft-L. Having thus fixed the surround brightness, sufficient flashes of various wavelengths and intensities were administered for determination of relative spectral sensitivity. Spectral curves were found for three conditions of central field illumination: (1) central field unlighted; (2) central field filled with blue light; and (3) central field filled with red light. The hypothesis was that a mixed photopic-scotopic spectral curve would be found when the central field was unlighted. Since the photopic mechanism is known to be quite sensitive to red light, it was anticipated that red adaptation would "condition out" photopic activity leaving a scotopic spectral curve; blue adaptation was expected to produce the opposite result.

Part 2. The chief difference between the two phases of the experiment was in the surround luminance which was raised to 2 ft-L in Part 2. This more intense adaptation changes the ERG so that only a single positive wave is present. Spectral sensitivity was investigated for red, green, blue, and unlighted central fields.

For both parts 1 and 2, the central fields were operated at the same intensities as given in Figure 3.

Determination of Relative Spectral Sensitivity. The same procedures as described in detail by Riggs, Berry, and Wayner (4) have been used to compute relative spectral sensitivity. Data relating the height of the ERG and stimulus intensity were collected for stimuli spaced throughout the visible spectrum. After these data had been plotted, the intensity needed to produce definite amplitude of response could be found. Calibrations of the interference filters together with the neutral filters enabled the experimenter to compare responses from various spectral regions.

RESULTS

Part 1. The dual nature of the activity found in the first phase of the experiment is seen in Figure 4. With only the surround illuminated (top row of Figure 4), a large response occurs with test flashes of all colors. Of the two peaks which appear in response to red flashes the first is the X wave, and the second is the B wave. If other than red test flashes are utilized the B wave component becomes larger, and its latency is decreased.

Thus, it may com-
pletely overshadow the
X wave. Filling the
central region with
red adaptation light
eliminates all detecta-
ble response to red
flashes (middle row of
Figure 4). B waves
of somewhat reduced
amplitude follow stim-
ulation with shorter
wave lengths. With a
blue central field (bot-
tom row of Figure 4),
no detectable B wave
and only a small X
wave potential is de-
veloped.

Figure 4. Responses under conditions of mesopic adaptation. The row labeled "no adaptation" shows responses with the central field un-lighted but with a surround luminance of 0.006 ft-L. Red or blue adaptation reduce response from their respective parts of the spectrum. Subject JA.

Figure 5 shows
plots of the height of
response versus stim-
ulus intensity. Two
distinct rates of increase in the height of re-
sponse with stimulus intensity may be discerned.
The gradually sloping curves found with a blue
central field previously have been found to be
typical of photopic responses (3). On the other
hand, an "S-like" curve as found with red adap-
tation is characteristic of the scotopic B wave.
The two forms of curve add to give the result
obtained with an unlighted central field.

Figure 6 is a plot of the relative spectral
sensitivity of $25\,\mu V$ and $100\,\mu V$ responses for the
unlighted central field condition. The $100\,\mu V$
curve gives evidence of scotopic activity alone,
but the high sensitivity of $25\,\mu V$ responses for
red light suggests mixed photopic-scotopic ac-
tivity. This result follows from the rapid rate
of increase in the B wave with stimulus intensi-
ty. Figure 7 is an example of how $25\,\mu V$ re-
sponses may be manipulated to yield either pho-
topic or scotopic luminosity curves depending
upon the color to which the eye is conditioned.

Figure 5. Plots of the amplitude of re-
sponse versus stimulus intensity. Note how
these curves change in character with the col-
or of adaptation. Lines have been drawn
through the experimental points by inspection.
Each point represents an individual response.
In this figure a 0.0 stimulus of any given
wave length is of the same intensity regard-
less of adaptation, but 0.0 stimuli of differ-
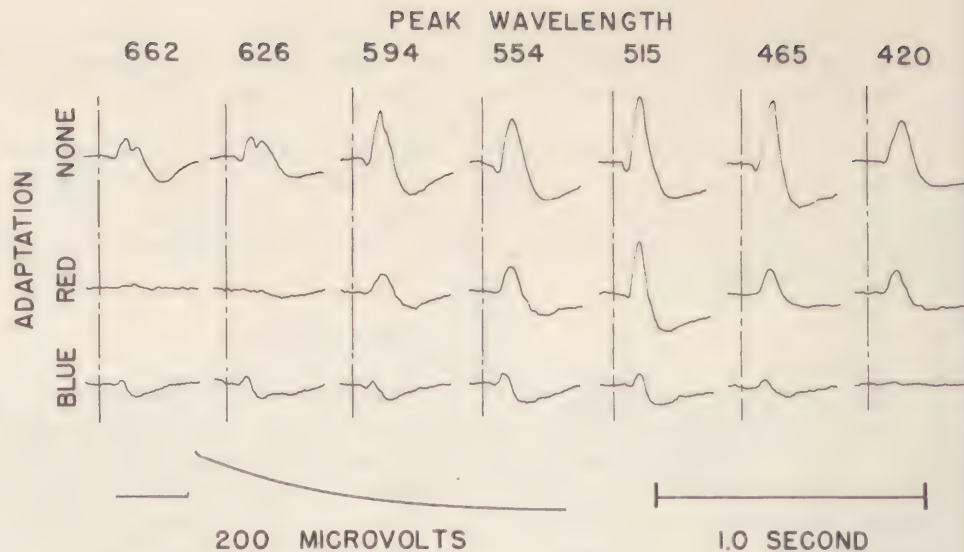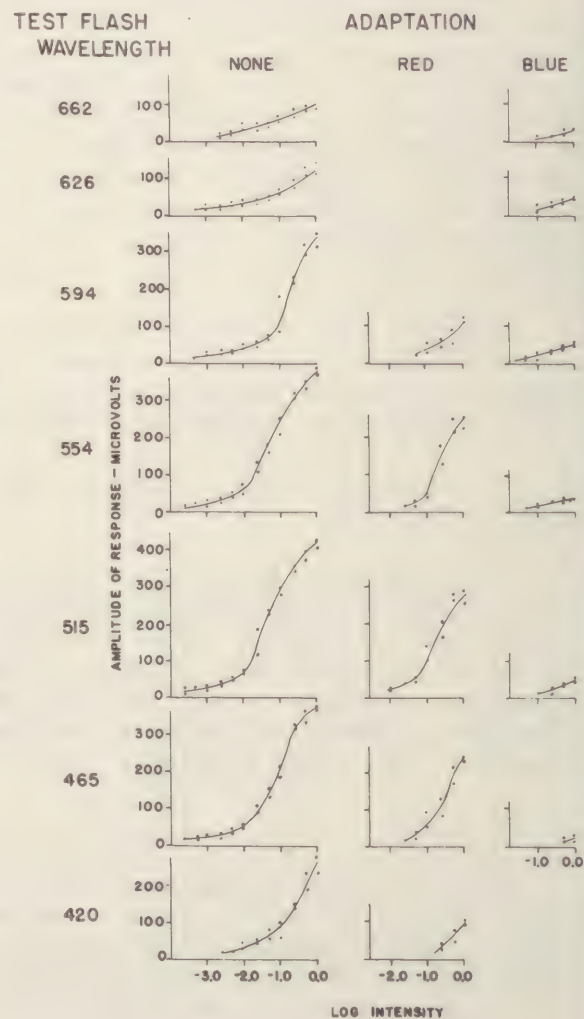ent wave lengths have not been equated for
energy content. Subject JA.

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Figure 6. Spectral sensitivity of the ERG with neutral low level adaptation. The smooth curve is the Stiles and Smith scotopic function (6). Straight lines connect experimental points. Large responses (100 μV criterion) exhibit scotopic features while smaller ones (25 μV criterion) give evidence of both photopic and scotopic activity. Subject JA.
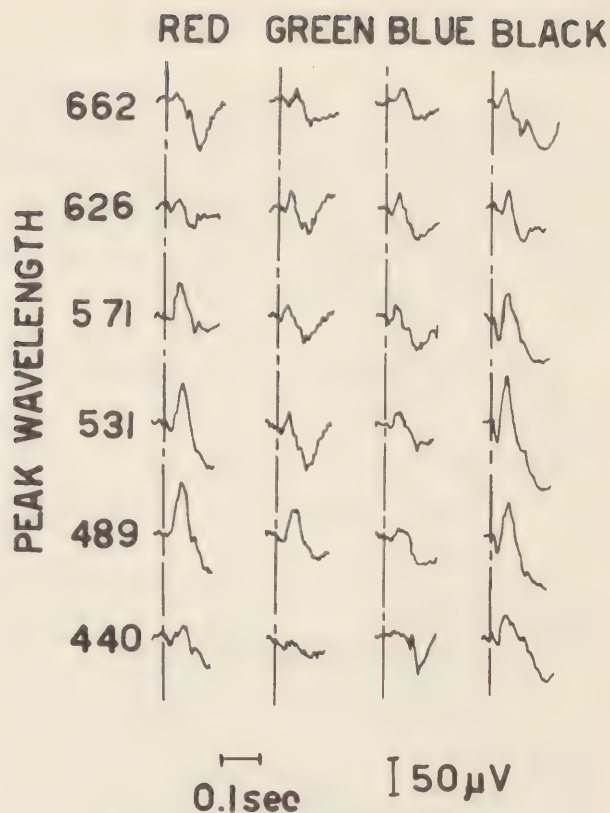
Figure 8. Responses found with a 2 ft-L surround and colored central adaptation fields. Color adaptations produce a reduction in response to test flashes throughout the spectrum, but the reduction is greatest in a restricted region. Subject JA.
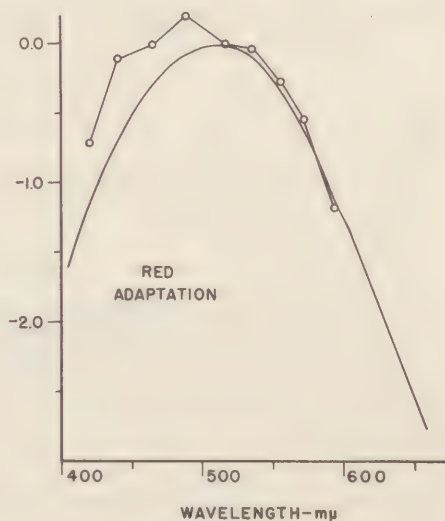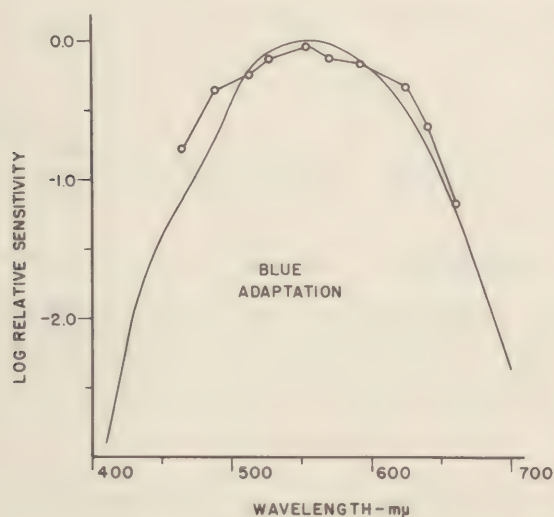
Figure 7. Spectral sensitivities of selectively adapted activity. With blue adaptation response sensitivity matches the ICI photopic luminosity curve shown by the smooth line. With red adaptation sensitivity approximates the Stiles and Smith scotopic curve. Subject JA; 25 μV criterion.

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That is, red adaptation yields a scotopic function; blue adaptation makes the function pho-
topic.

Part 2. The second part of the experiment differed from the first in the surround
luminance which was increased to 2 ft-L. Responses in all cases were of a single pointed
variety (Figure 8), thus, in all gross respects resembling those which have been described
for the X wave. Nevertheless, although wave form alone offers little evidence of more
than one underlying activity, comparison of the tracings will reveal that response to a par-
ticular spectral region is reduced in size when the eye is subjected to adaptation from the
same or closely adjacent regions.
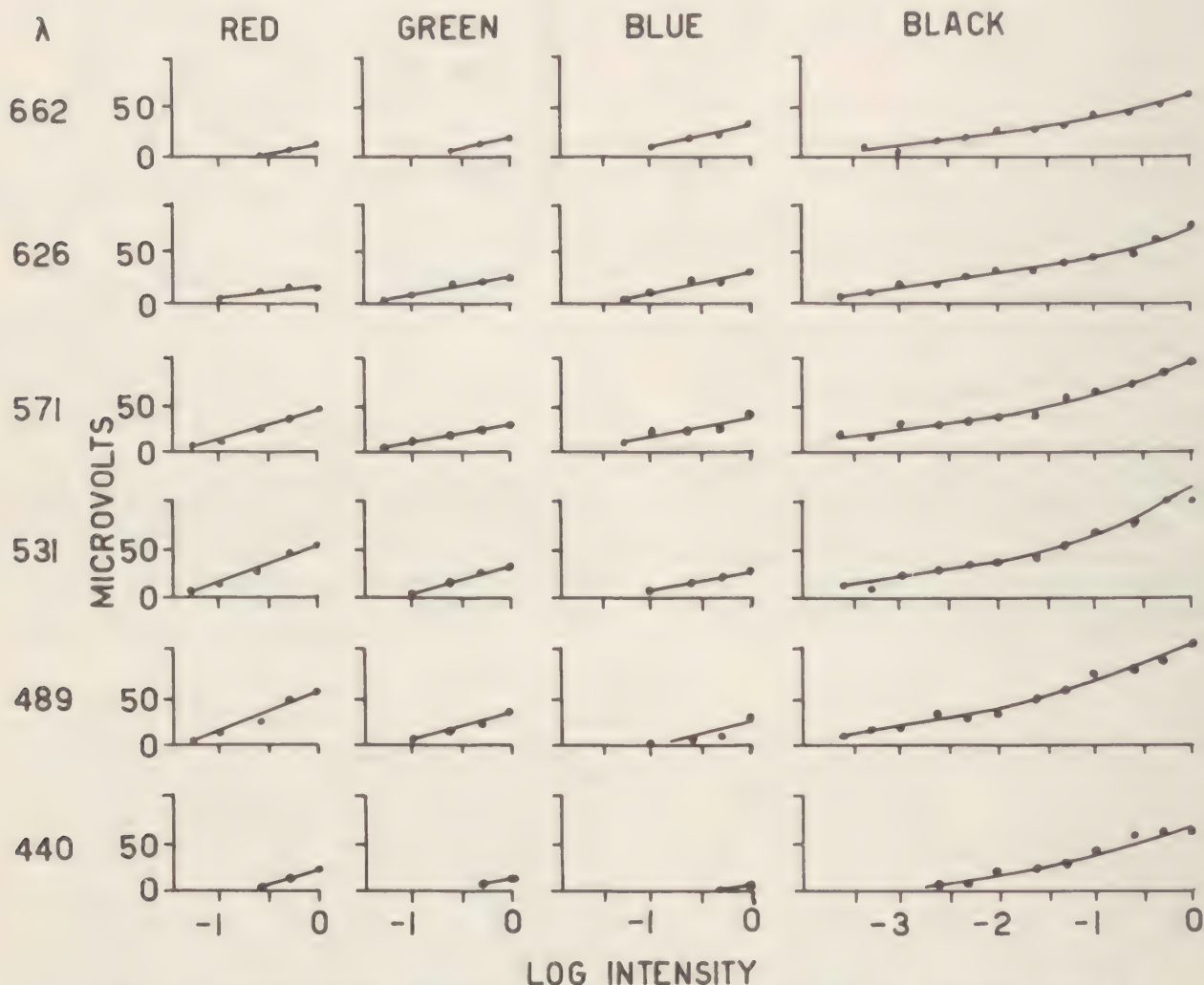
Figure 9. Sample curves relating the height of response to stimulus intensity with a 2 ft-
L surround. Each point is the average height of seven responses. Except for curved data found
with a black or unlighted central field, straight lines have been fitted by the method of least
squares. In this figure a 0.0 stimulus of any given wave length is of the same intensity regard-
less of adaptation, but 0.0 stimuli of different wave lengths have not yet been equated for energy
content. Subject JA.

Typical plots of response height versus stimulus intensity are given in Figure 9 where
each point is the average of seven responses. The abrupt "S-like" curves which were com-
mon at the lower level of adaptation are not found here. A moderate slope is in all cases
characteristic, thus, suggesting that only photopic activity is being recorded. Nevertheless,

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there is some tendency for a greater slope when responses are elicited by blue test flashes. The effect is most striking with red adaptation where the blue response is relatively more active. Also to be noted in Figure 8 is the selective effect of colored adaptation. With green adaptation the curves for yellow and green activities are displaced along the intensity axis towards the right or the high intensity regions. With red and blue adaptations very little response at all could be found in the corresponding spectral regions.

Figure 10 is a plot showing the relative spectral sensitivity of $25\,\mu V$ responses for the various adaptation conditions of Part 2. The data make it evident that an appreciable degree of selective adaptation has been produced even though only a single wave may be seen in the original records.

The full significance of the present data will only be revealed by further experimentation. The results show that operations similar to those conducted in the psychophysics of color may also be carried out with the ERG. Thus, it appears that a direct method for investigating the color activity of the retina is now available.
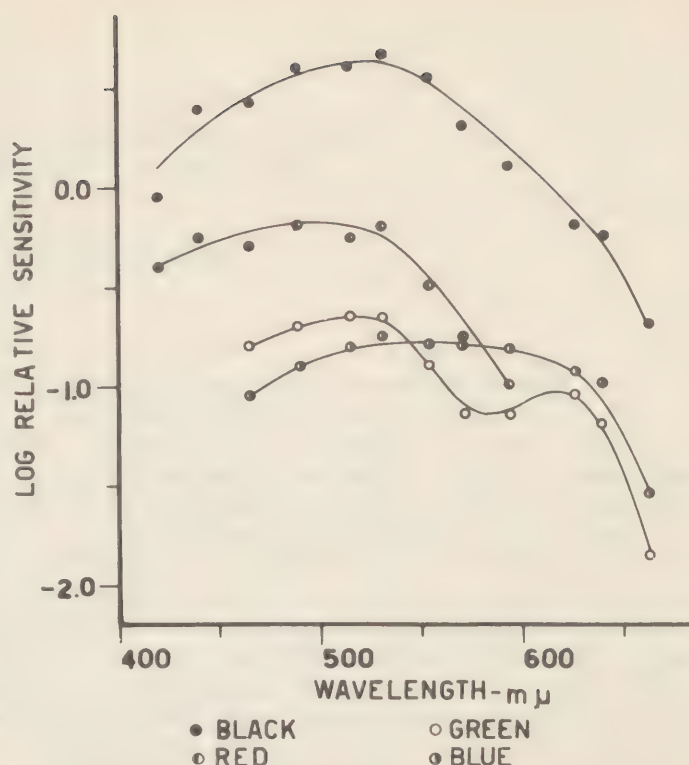
Figure 10. Effects of selective adaptation upon the light adapted electrical response. Colored adaptations lower sensitivity to their particular part of the spectrum. Upper curve was found with an unlighted central field; $20\,\mu V$ criterion. Subject JA.

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A GENERAL METHOD FOR INVESTIGATING THE
EXCITATORY STATE OF THE RETINA

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Department of Psychology
Yale University

A method of investigating the excitatory state of the retina in response to any arbitrary spatial distribution of light intensity will be described. The method will be validated in terms of the area-intensity relationship. The theory which generated the method will be mentioned. The application of the method to a wide range of visual stimulation patterns will be proposed. It will be suggested that the method will yield some new information on the problems of simultaneous color contrast, the Mach effect (border contrast), the geometrical illusions, the problem of closure, and the Gibson gradients. These last examples define the range and type of problems capable of being handled by the method. Let me illustrate the generality of the method by the following question. Is it possible to describe the spatial excitatory state of the retina to such complex stimulation as an auditorium, the stage of a theater, the quiet chiaroscuro of a snow-clad mountain at dawn? The method I am going to describe is new only in its application. It is a generalization of the contrast threshold method. Some of you here may have thought of it already.

Simple-minded as it might seem at first glance, it is proposed to determine the threshold intensity for a point source of light as a function of its position up and down and along the field of visual stimulation. To be specific, if a tiny spot of light could be projected on the wall, and the threshold for that spot could be determined for many regions of the wall, then it is believed that the set of thresholds would mirror the underlying excitation pattern produced by the light pattern of these auditorium walls.

Such a set of threshold determinations might be made, but what would they mean apart from their status as data, or as my son might say, so what? Clearly three things need to be known: (1) What are the effects of varying the brightness, the spatial rate of change of brightness, the spatial acceleration of brightness, and the introduction of brightness discontinuities? (These are all abstracted variables.) (2) What is the effect of variation in method? Are there differences between the case where the test spot moves and the eye is fixated and the case where the eye fixates the test spot as it is tried in various positions of the visual field? (3) Can the method be validated where there are excellent reasons to infer that there are excitation patterns that differ from the brightness pattern? The last question is fundamental, because, in order to validate a "new" method, or rather a new application of an old method, it must yield critical information on an old problem where the answer is already known.

Let us backtrack then for a moment and consider the problem of the area-intensity relationship as it was handled by the proposed method. The validating research was carried out by Kruger, Boname, and Reiss at Yale last year. A disk of light was exposed to a subject. The brightness was adjusted until the disk was just above threshold.

The brightness was such that the disk was easily seen. According to Graham's hypothesis and the data and observations of Graham, Brown and Mote (3), the threshold for an exploring point source would be expected, even redundantly, to be lower at the center of the disk than at the edge. Therefore, if the proposed method is valid, then the threshold should be lower in the center.

Figure 1 presents the data for two subjects. The disk was 3.71° diameter and was centered 18° 45' out on the temporal retina of the right eye. The curves labeled "A" are the thresholds for the exploring test light when the disk is absent. The curves labeled "B" are the thresholds for the exploring test light when the disk is visible. It is clear from inspection that the "B" curves show a dip in the center of the
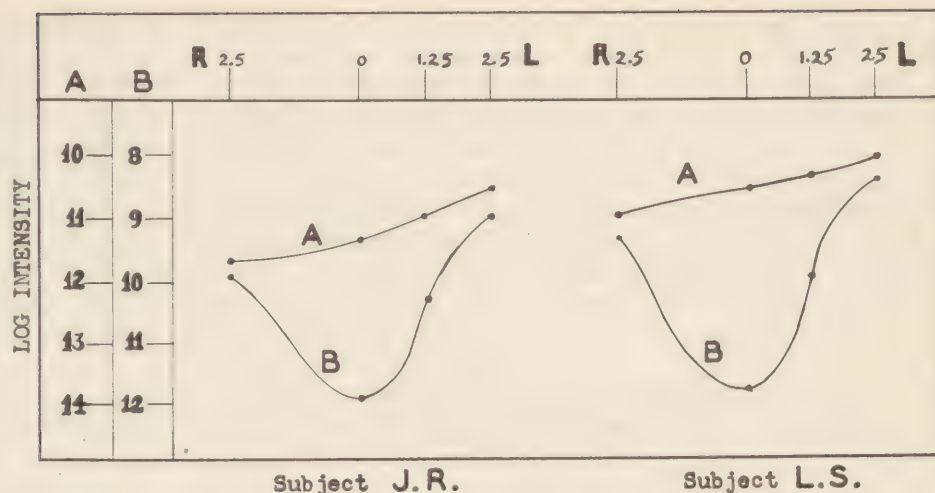

Figure 1. A General Method for Investigating the Excitatory State of the Retina.

disk. The outlines of the disk are delimited by the coordinates at the top of Figure 1. The relative intensities in terms of the settings of a logarithmic wedge are given vertically on the left-hand side of Figure 1. Each point is the average of four days data and each day the average of four ascending and descending determinations. Both subjects had been trained to their limit of reproducibility prior to collecting the critical observations. The position data are significant by days at the 0.1% level. The data offer primary validation of the method we propose here.

Others have used the method in vision: Sloan (7), Crozier and Holway (2), Holladay (4), and lately Riopelle and Bevan (6), but they have not generalized it. It is the formal classic method in hearing when one studies the effect of masking through the use of an exploring test tone. All that is new here is its application.

Let us name this method the field method in that it is analogous to the ideal of a hypothetical test charge in electric field theory.

What are some of the methodological and conceptual difficulties we can anticipate? These can best be stated as questions.

(1) How do we know that introducing the test spot does not interfere with the visual excitation field? The answer is: we don't know. But what is more important we shall probably never know except ideally by extrapolation. Actually, the question if pursued becomes indeterminate because it is related to the class of questions: How can one measure anything without affecting the process that is being measured?

(2) How does the present method relate to the notion of $\Delta I/I$? It is believed, on theoretical grounds (the elements of which will be given later), that the expression for contrast sensitivity may have to be revised to state that ΔI as a measure of the excitation is some function if I. Specifically, the studies on contrast sensitivity where small test lights are used (possibly within Blackwell's (1) concept of critical area) are reinterpreted as yielding ΔI at a point as a function of the brightness of the surrounding areas.

(3) How does one produce experimentally any preassigned set of brightness patterns? Shapes and sizes such as disks, squares, etc., that are to be of uniform brightness are easy. But the problem of producing spatial changes of brightness which can be altered readily is technically not easy. Continuous linear brightness changes are easy to get once one has read Middleton's article (5). Sharp discontinuities are easy, but non-linear and spatially aperiodic brightness patterns present completely unsolved problems.

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(4) Then there is the problem of presenting the patterned visual field and the exploring test spot. Here there seem to be five solutions; each has its difficulties. First, there is the direct method we have already presented, projecting a test spot on reflecting objects in the excitation field. Second, there is the method of projecting both test spot and a set of excitation patterns on a diffusely reflecting surface. Third, there's the method of projecting the test spot and the excitatory patterns on opposite surfaces of a thin diffusely transmitting and diffusely reflecting surface, such as etched flashed opal glass. Fourth, there's the method of reflecting and transmitting the test spot and excitation pattern off the front of and through a half-silvered mirror or piece of thin glass inclined at 45° to the line of sight. Fifth, there is the method of the oscilloscope screen in which the excitation patterns and test spots can be introduced electrically much as in a television receiver.

(5) The fifth major problem is interpretation. Here, two things are needed: A lot of work and a lot of heavy thinking. Three initial guiding ideas can be summarized as follows:

These problems can be approached as specific empirical problems to gain understanding of old observations: the geometrical illusions, simultaneous brightness contrast, the Mach effect, the problem of border gradients, the Gestalt figures may yield to the present analysis, simultaneous color contrast, the constancies, apparent movement, etc., the list covering the range of visual phenomena.

The second guiding idea depends upon theory. While a wide range of theories may be possible, the method of test spot exploration of a patterned visual field resulted as one interpretation of the notion that the excitation at any point in the retina is a function of the successive spatial derivatives of brightness in the neighborhood of the point. But the method of measuring the visual excitation field by means of the threshold for an exploring test light is quite independent of theory although it was generated by theory.

The third guiding idea consists in applying the experimental method to a single individual. This last notion is best illustrated by an example. Let us suppose that the visual excitation field has been mapped in terms of the exploring probe light for a given brightness pattern. Let us now alter any one element in the pattern and remap the field. Any differences between the two mappings are attributable to the change in the single element. Thus it should be possible to study interaction effects that occur by determining the regions of the visual field affected.

In closing, the method of measuring the visual excitation field can be validated in terms of the area-intensity effect, might yield new information on old problems such as the optical illusions, might provide the basis for new theorizing, offers a possibility of using the experimental method to assess visual interaction. Research will tell.

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ANNOUNCEMENT BY DR. STANLEY S. BALLARD, CHAIRMAN OF THE USA NATIONAL COMMITTEE OF THE INTERNATIONAL COMMISSION OF OPTICS

Dr. Ballard said a few words about a new European optics journal OPTICA ACTA, and also spoke concerning the International Commission of Optics, which organization has assisted in the launching of this new journal. The ICO is a commission of the International Union of Pure and Applied Physics. However, its charter clearly states that the field of "visual optics" is included within its cognizance. Therefore, the Vision Committee should be kept well informed as to the activities of the ICO. The most recent ICO Congress was held in Madrid, Spain, in April of 1953 and the accompanying scientific sessions were largely devoted to topics in physiological optics. It has been proposed that the next regular Congress (scheduled for 1956) be held in the USA, and consideration is now being given to the many practical problems associated with such an enterprise.

Two symposia of interest to optical people were mentioned: The ICO is sponsoring a symposium on infrared instrumentation to be held in Parma, Italy, on 3-7 September 1954. This will be closely followed by a symposium on "Problems in Contemporary Optics" sponsored by the National Institute of Optics of Italy and held at the Institute, in Florence, during the period of 10-16 September. Dr. G. Toraldo di Francia is the organizing spirit of the latter meeting.

The National Research Council has recently reconstituted the USA National Committee of the ICO; a number of members of the new committee are well known to workers in the visual field. The entire roster of the committee as presently constituted is as follows: Messrs. B. H. Billings, H. S. Coleman, G. A. Fry, I. C. Gardner, F. A. Jenkins, · D. B. Judd, R. Kingslake, H. A. Knoll, K. N. Ogle, J. H. Webb, and S. S. Ballard, Chairman.

A copy of the OPTICA ACTA was exhibited--this is Volume 1, No. 1, dated January 1954. It was noted that the blue of its cover is perhaps complementary to the yellow cover of the JOURNAL OF THE OPTICAL SOCIETY OF AMERICA and that it is hoped that this complementarity will extend to geographical coverage of subject matter, so that these two journals may some day jointly dominate the optical publication picture and thereby simplify the current situation in which there are half a dozen small, struggling European journals of optics. Arrangements are being concluded for the American Institute of Physics (57 E. 55th Street, New York 22, N. Y.) to serve as the subscription agency in the USA for OPTICA ACTA. A $10 check will establish a subscription for the current year. The AIP has a few examination copies of this first number and will doubtlessly send them out, on request. The second number is believed to be in press at the present time.

REPORT OF THE EXECUTIVE COUNCIL

Dr. Berens expressed the thanks of the Committee to Dr. Henry Imus, Dr. Richard Trumbull, and Lt. Hickey for making local arrangements for the meeting of the Committee.

Dr. Berens announced the election of three new associate members of the Committee: Dr. Thomas G. Dickenson, Dr. Elwin Marg, and Dr. Harry Helson.

Dr. Berens announced that Dr. H. Richard Blackwell had consented to continue as Executive Secretary, in spite of his expressed desire to resign.

Dr. Berens announced the election of Col. Harry J. King, Jr., as Deputy Chairman of the Committee, and his own reelection to the Chairmanship.

Dr. Berens announced that the fall meeting of the Committee would be held in Toronto, November 4-5, 1954.

ABSTRACTS

A Preliminary Field Evaluation of the Relative
Detectability of Colors for Air-Sea Rescue
Malone, Florence L.
Medical Research Laboratory Report No. 237
Bureau of Medicine & Surgery, Navy Dept.
23 November 1953   9 pp.

"This study investigated the relative detectability of Munsell reds (10YR to 10R 6/10, 5/10), fluorescent paints, International Orange, and the standard lifeboat yellow.

"Observations were made from a P4Y-IP aircraft flying at altitudes of 1000 and 500 feet and at distances of three quarters of a mile to one and three quarters miles from the targets. The targets were spheres of spun aluminum, 34" in diameter, which were towed in groups of five by a retriever. Observations were made during the spring and summer on sunny days with a minimum of haze.

"Colors from 215 Red to 7.5 Red were detected first and second a significantly greater percentage of the time than the standard lifeboat yellow. The fluorescents and International Orange also showed greater detectability than lifeboat yellow."

Effect of Refractive Error on Acuity Through
Binoculars
Kinney, Jo Ann Smith, and Cornelia H. Pratt
Medical Research Laboratory Report No. 245
Bureau of Medicine & Surgery, Navy Dept.
2 April 1954   11 pp.

"A study was made of visual acuity through binoculars, and of the extent to which refractive errors can be corrected by adjusting the eyepieces of standard binoculars. The acuity of individuals with varying types of refractive error was measured by a liminal method using various dioptric settings in the binoculars and was shown to be best at the setting indicated by the results of refractions.

"The acuities of a group of naval enlisted men were tested using their optimum binocular settings and a comparison made between the performance of men who did and did not have unaided acuity of 20/20. Individuals whose unaided acuity was poor, due to simple spherical errors performed as well with binoculars as those whose unaided acuity was 20/20. Type of refractive error was shown to give a more adequate prediction of the individuals who perform well with binoculars than does the 20/20 standard.

"It was found that astigmatism of less than one-half diopter did not impair acuity under any of the conditions tested, but larger amounts had a marked effect."

Design of a Color-Matching Dosimeter
White, C. T.
U.S. Naval Electronics Laboratory
San Diego, California
23 November 1953   4 pp.

STATEMENT OF PROBLEM: "Design an ideal step-matching dosimeter for atomic radiations. This report describes the design of a color-matching personal dosimeter to be compatible with human visual capabilities.

CONCLUSIONS:

"1. On the basis of evaluation of the alkali halide dosimeter of the IM-56 (XN-3)/PD type it was concluded that such a dosimeter should be useful as a tactical screening device for detecting personnel who have been exposed to dangerous amounts of atomic radiation.

"2. A color-matching device of the alkali halide, self-indicating type is not suitable for accurate quantitative readings.

"3. Certain basic factors should be taken into consideration whenever a color-matching display is being designed:

   a. Color contrast effects must be minimized· (proper background, spatial relationships).

   b. All colors should be of the same type (volume, film, or surface).

   c. The display should be designed for monocular viewing if possible, especially when volume colors are involved.

RECOMMENDATIONS:

"1. The display used in the IM-56(XN-3)/PD should be incorporated in production models of the alkali halide dosimeter.

"2. No further development should be carried out in the design of the visual display of this dosimeter.

WORK SUMMARY: "The visual display of self-indicating dosimeters of the IM-56 (XN-3)/PD type was studied, modified, and evaluated. The actual development of the dosimeters studied was carried out by the Eastman Kodak Co., the Callery Chemical Co., and the Polaroid Corporation. The reports prepared by Dr. William A. Shurcliff of the Polaroid Corporation have been especially helpful in providing a knowledge of the technical problems involved and in tracing the development of dosimetry.

"The Laboratory personnel involved in this problem have been M. W. Lund, P. G. Cheatham, and C. T. White."

Visual Field Restriction and Apparent Size
of Distant Objects
Imber, Burton M., Irwin D. Stern, and
James M. Vanderplas
Aero Medical Laboratory
Wright Air Development Center
WADC Technical Report 54-23
January 1954   12 pp.

"It is well established that the apparent size of distant objects is reduced when they are viewed through a telescope of unit power having a restricted field of view. Previous studies have not given a fully satisfactory explanation of this phenomenon. The present study was an attempt to isolate the factor of visual field restriction, without optical magnification, and to determine what effect, if any, this kind of restriction in the visual field has upon the apparent size of distant objects.

"Four observers made judgments comparing the apparent size of a variable-sized white square, set at a distance of 500 feet and viewed monocularly through an aperture,

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with the apparent size of a standard 20-inch square, viewed binocularly at a distance of
30 feet. Aperture sizes from 5 to 60 degrees were used to restrict the visual field. The
psychophysical Method of Constant Stimuli was used as a sensitive measure of the effects
of aperture size on the apparent size of the distant objects.

"The results indicate that no consistent decrease in apparent size results from visual
field restriction per se. It was found that a slight (2 per cent) but consistent increase in
apparent size occurred with all apertures used, but this effect was not found to be corre-
lated with aperture size. It is hypothesized that slight overestimation of distance by the
observers under the conditions of the study may have resulted in the apparent size in-
creases found. It is suggested that factors inherent in optical systems may account for the
large decreases in apparent size found when telescopes or periscopes are used."

Visual Contrast Discrimination as a Function
of Pre-Exposure to Light
Mote, F. A., W. R. Biersdorf, G. W. Kent, and
Jerome Myers
University of Wisconsin
Wright Air Development Center
WADC Technical Report 54-80
February 1954   12 pp.

"The just discriminable brightness contrast threshold was measured for 12 subjects
(six using the natural pupils, six with 2 mm. artificial pupils) at three values of target
luminance following pre-exposure to a constant intensity for three durations. Each subject
went through all nine combinations of conditions five times.

"The duration of pre-exposure had little effect upon contrast sensitivity when the high-
est target luminance was used. At the middle value of target luminance, the longer the
pre-exposure the higher the contrast threshold upon termination of pre-exposure and the
slower the recovery of maximum sensitivity. When the lowest target luminance was used
(a value near the dark adapted threshold for the fovea), the effect of pre-exposure was
marked. For all durations, when artificial pupils were used, the initial threshold following
pre-exposure was high and the speed of recovery depended upon the duration; the longer the
duration, the slower the speed. When natural pupils were used the initial threshold con-
trast ratio was about 0.3 and recovery of maximum sensitivity was rapid. At the two long-
er durations there was a delay of the order of 15-50 seconds before an initial setting could
be made at maximum contrast (0.53) and the recovery of maximum sensitivity was greatly
retarded."

Scale Design for Reading at Low Brightness
White, William J., Shirley C. Sauer
Aero Medical Laboratory
Wright Air Development Center
WADC Technical Report 53-464
March 1954   16 pp.

"This study concerns the manner in which speed and accuracy of quantitative scale
reading varies as a function of graduation mark width and interval size under three intensi-
ties of red illumination such as are encountered in cockpits at night.

"The data of the experiment consist of time and error scores obtained by different
subjects, each under the same varying conditions. Graduation mark width varied from
0.008 inch to 0.063 inch and graduation intervals varied from 0.05 inch to 0.25 inch.

"The results of the study permit the following conclusions concerning the dimensions
of scales for the visual presentation of quantitative information at the viewing distance

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(28 inches) and minimum night lighting conditions (.01 to .002 foot lamberts) normally found in aircraft cockpits: For optimum speed and accuracy of instrument reading (1) the distance between adjacent scale marks (graduation interval) should not fall below 0.11 inch; and (2) the width of the minor graduation marks should be approximately 0.032 inch."

The Effect of Luminance and Exposure Time
Upon Perception of Motion
Leibowitz, H. W., J. F. Lomont
University of Wisconsin
Wright Air Development Center
WADC Technical Report 54-78
March 1954   9 pp.

"The isochronal threshold velocity is defined as the minimum rate of target displacement necessary for the detection of movement at a constant duration of exposure. Threshold values were obtained for a wide range of luminance values in foveal vision at various durations of exposure. The function relating motion perception to luminance decreases as luminance is increased, rapidly at first and then more slowly, as the data approach a limiting value. The effect of an increase in exposure time is to shift the entire function to lower threshold values as well as to minimize the effect of luminance in decreasing the threshold velocity.

"The perception of movement is more precise the higher the luminance and the longer the exposure time. The lowest thresholds, however, are obtained at the longer durations, and it is recommended that exposures of more than two seconds be employed when detection of target motion is important. Such long exposures produce the lowest thresholds even under poor conditions of luminance."

Tracking Performance as Measured by Time
Continuously on Target
Archer, E. J., L. D. Wyckoff, F. G. Brown
University of Wisconsin
Wright Air Development Center—TR 54-210
March 1954   15 pp.

"Twenty Ss divided into two groups corresponding to fast and slow target speeds practiced on two Mast Pedestal Sight Manipulation Tests (PSMT) for five days each. In addition to the usual cumulative time-on-target per trial, a new performance measure was obtained. A Continuous-Time-On-Target record was activated whenever the operator scored on azimuth, elevation, and range (AER) simultaneously. This recorder had 12 interval-counters which fired successively depending upon how long S continuously scored on AER. The intervals which were recorded ranged from 0.00 sec. to 3.2 sec. in unequal steps.

"It was expected that as S became better practiced on this complex task the frequency of longer duration 'hits' would increase and probably the frequency of shorter duration 'hits' would decrease. In effect this would mean the mode of the frequency distribution of 'hits' would shift to longer durations rather than have a uniform increase in all hit durations. These expectations were confirmed.

"If this method of analyzing tracking performance were continued until Ss became very well practiced, it might even be possible to differentiate between stages of practice in terms of the frequency of long duration hits after cumulative times-on-target had attained an asymptote. After five days the AER scores had not reached an asymptote. Such knowledge could be of relevance in the design of gun-laying computers.

"Although no attempt was made to alter the characteristics of the PSMT units, except to vary the speed of targets, it seems reasonable to suppose that the continuous-time-on-

target method of analyzing tracking performance could provide a more useful method for evaluating the design of gunnery equipment since in this method frequencies of hits of given duration will be governed by man-machine periodicities."

Routine Maneuvers Under Day and Night Con-
ditions, Using an Experimental Panel Arrangement
Cole, Edward L., John L. Milton, Billy B. McIntosh
Aero Medical Laboratory
Wright Air Development Center
WADC Technical Report 53-220
March 1954   51 pp.

"This report is the ninth in a series of investigations of eye movements of pilots during instrument flight. The frequency, duration and sequence of eye fixations made by 15 pilots when flying day straight and level, level turns, climbing turns, straight dives and 180-degree time turns, and during night straight and level and level turns with a new panel arrangement are summarized. Comparisons are made between the maneuvers flown under day and night conditions. Also, for comparison of standard and experimental panel arrangements, data previously obtained using the standard Air Force panel during routine maneuvers under day conditions are included. Under all conditions the directional gyro, gyro horizon, vertical speed, airspeed and altimeter are the most used instruments.

"Significantly more and shorter fixations were made during day level turns than for night level turns. Significantly longer fixations were made on the instruments during night straight and level flight than for day straight and level flight. The total number and average length of fixations during straight and level, level turns and 180-degree time turns were significantly more and shorter on the experimental panel than the standard panel during these maneuvers. There were significant differences between panels for number and length of fixations on some of the individual instruments. Considering the results of this study and the results of other studies, which show that the optimal spacing between instruments is short and horizontal, and that instruments in the top row tend to be fixated first and more frequently, the standard panel represents a better instrument panel arrangement for routine maneuvers."

A Velocity Modulated Raster Display for Bright-
ness Discrimination Studies
Barger, Dale M., Robert G. Roush
The Johns Hopkins University
Wright Air Development Center
WADC Technical Report 53-249
August 1953   6 pp.

"The equipment described in this paper, using two standard and one modified oscilloscopes, was designed as a research instrument for the study of human brightness discrimination. Its basic function is to produce a rectangular light field consisting of a raster of vertical sweep lines on a cathode ray tube face. Independent control of the brightness of each vertical sweep line in the raster permits study of the ability of observers to detect differences in brightness in the light field as a function of the brightness differences between adjacent homogeneous fields, the relative size of adjacent fields, and the brightness contour or gradient which exists between two fields homogeneous in brightness.

"The detection of brightness differences on the raster can be studied by requiring observers to make verbal judgments about the apparent differences seen, or, if desired, they can be required to adjust a second raster to match the pattern of brightnesses seen on the first."

Studies of Detectability During Continuous
Visual Search
Deese, James, Elizabeth Ormond
The Johns Hopkins University
Wright Air Development Center
WADC Technical Report 53-8
September 1953   48 pp.

"This report describes a series of experiments on visual search. The task employed in these experiments was a search for isolated targets that appeared from time to time on a single sweep of a PPI-type cathode ray tube. A number of variables were studied, of which perhaps the most significant is the rate at which targets appear. Probability of detection was studied for different average rates of target appearance. The results clearly showed that low rates of target presentation produce a very much lower probability of detection than do high rates. Targets presented at the average rate of 10 per hr. are detected about 66% of the time or less, whereas targets presented at an average rate of 40 per hr. are detected about 90% of the time or more. There is every reason to believe that lower rates of target appearance would produce even lower probability of detection. This fact, in conjunction with a finding of no relationship between inter-target time interval and detection (or the possibility of a positive one rather than the predicted negative one), leads to the formation of a hypothesis of level of search behavior in terms of expectancy. A number of other variables were studied, including the observer's knowledge of length of search period and the actual length at search. Different lengths of search produced different curves of probability against time at search. These different curves all had about the same average value, however."

An Experiment on Dial Coding
Cohen, Jerome, Virginia L. Senders
Antioch College
Wright Air Development Center
WADC Technical Report 52-209
November 1953   16 pp.

"Three equated groups of subjects were tested over a five-day period on their ability to locate and check-read an instrument on a simulated instrument panel. On the sixth day, the locations of the instruments on the panel were changed, and the subjects were asked to locate instruments on the rearranged panel. The control group was tested on a panel on which all thirty-two instruments were identified only by labels; another group was tested on a panel on which instruments were, in addition, identified by a color code; and a third group was tested on a panel on which instruments, besides being labeled, were identified by a shape code. Except on the early trials, the control group was slower and more variable than either experimental group, and made more errors in locating instruments. Differences between the experimental groups and the control group were greatest for the rearranged panel. The color-code group showed, in general, a better performance than the shape-code group. From these results it is concluded that coding will improve dial checking performance, but a formal system of coding may not be necessary, since differences in labels, graduations, and numerals already form a code."

Visual Performance as a Function of the Bright-
ness of an Immediately Preceding Visual Task
Spragg, S. D. S., Joseph W. Wulfeck
University of Rochester
Wright Air Development Center
WADC Technical Report 52-285
December 1953   16 pp.

"This study, part of a project on human factors in aircraft instrument lighting, has undertaken to determine how visual performance at low photopic brightness levels is affected

by the brightness of an immediately preceding visual task. Two visual tasks were employed. In one, called the near task, subjects were required to read banks of photographic reproductions of instrument dials under instructions stressing speed and accuracy. The viewing distance was 28 inches, and three task brightnesses were employed: 2.9, 0.083, and 0.005 foot-lamberts. In the other, called the far task, subjects 'read' banks of Landolt rings with speed and accuracy instructions. These were viewed periscopically at a distance of 18 feet, and five task brightnesses were used: 6.0, 0.076, 0.01, 0.007, and 0.0035 foot-lamberts. Subjects were high school and college students with excellent visual abilities. In Experiment I, subjects (N = 15) were visually adapted to the brightness level of the near task, performed the near task, then immediately were given the far task. All combinations of near and far brightnesses were used in a balanced experimental design. Experiment II was similar in all respects except that the subjects (N = 12) first performed the far task, then the near task. A third experiment was also carried out as a corroborative check on Experiment II.

"Analysis of the data was primarily in terms of time scores. Results of both the near-to-far and the far-to-near experiments showed that, within the brightness ranges used, performance on a visual task was related to the brightness of that task but bore no general relation to the brightness of the immediately preceding visual task. Comparison of these results with earlier studies suggested that the critical 0.02 foot-lambert level of dial brightness previously found for this task can safely be exceeded by one, and possibly two, log units of brightness without impairing performance of a second, low photopic brightness task. It was emphasized that these findings refer to task brightnesses at and above cone threshold and to detailed visual tasks requiring foveal vision."

The Effect of Stimulus Size and Retinal Illuminance on the Human Electroretinogram
Marg, Elwin
Aero Medical Laboratory
Wright Air Development Center
WADC Technical Report 53-203
December 1953   18 pp.

"The purpose of this paper is to describe the changes in amplitude of the human electroretinogram (ERG) with varying retinal illuminance and stimulus size. The data is reviewed with particular reference to the effect of stimulus area on the ERG when the total luminous flux is constant.

"Measurements were made with both A.C. and a special converter (chopper) D.C. amplifier. Possible distortions of the A.C. amplifier were evaluated with the D.C. system. The electrodes were mounted in a contact lens on the eye and in a rubber cup on the forehead. The stimulus apparatus provided a 'Maxwellian view' with variable stimulus size from 5° to 41° and luminance up to 2600 millilamberts.

"As the size of the stimulus is increased, a marked change occurs in the ERG. Curves are presented to illustrate the course of the a-, b- and b-waves. The latter is a negative after-b-wave which may be part of the illumination potential of the retina.

"As the retinal illuminance was varied with different size fields, it was found that the luminous flux appears to be constant for the position of the maximum of the b-wave plot regardless of the size and luminance of the stimulus, within the error of measurement. However, the height (EMF) of these curves appears to be a function of area, becoming smaller with fields of increasing size. Hence, while stray (nonfocal) light is the primary stimulus in the ERG, an effect of area (focal light) appears to be demonstrated."

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